IMPACTS OF TRADE, ENVIRONMENTAL AND AGRICULTURAL POLICIES IN THE NORTH AMERICAN HOG/PORK INDUSTRY ON WATER QUALITY, TRADE PATTERNS AND WELFARE

by

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ABSTRACT

The objectives of this study were: (1) to design a framework to measure the impact of trade, agricultural and environmental policies on water quality and (2) to assess trade patterns and market welfare (Marshallian measures of producer and consumer surpluses plus government payments) under various combinations of agricultural, environmental and trade policies. To reach those objectives, an environmental model, EPIC, was linked to a model of the North American hog/pork sector.

Results show that trade liberalization does not contribute to water pollution in the two cases studies: Raleigh, North Carolina or Pont-Rouge Quebec. In fact, leaching of nitrates decreases in Quebec following the elimination of countervailing duties, stabilization payments and the ban on US live hog exports to Canada.

When nutrient management plans are implemented, both surface and groundwater quality increase. Environmental policies, including nutrient plans, also have a clear impact on trade patterns. The reduction in Quebec inventories triggers a decrease of Canadian live hog exports to the US and an increase of US pork exports to Canada.

Trade and agricultural policy scenarios have a larger impact on trade patterns than on welfare and water quality. When the ban on US live hog exports to Canada is lifted, US live hog exports to Canada increase at the expense of US pork exports and

Canadian live hog exports to the US.

Market welfare impacts from trade policies are different from impacts induced by environmental policies. Trade policy scenarios trigger increases in North American market welfare while environmental policies are responsible for decreases in market welfare. Since trade liberalization has a positive impact on welfare, the welfare decrease from environmental policy is somewhat attenuated under free trade conditions.

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CHAPTER 1 - INTRODUCTION

Problem Statement

The interaction between trade and environmental policies has become a hot issue in international policy forums such as the North American Agreement on Environmental Co-operation and the Committee on Trade and Environment (CTE) of the World Trade Organization (WTO). The topics raised include: 1) the impact of environmental policies on trade patterns and competitiveness, 2) the contribution of international trade to environmental degradation, 3) the international harmonization of environmental policies, and 4) the use of trade measures to ensure a given level of environmental quality. Dean (1992) identifies two important questions. First, will the removal of trade barriers decrease natural capital and lead to unsustainable development, annihilating the gains from trade? Second, if we assume that environmental policy can compensate for the potentially negative environmental effects of trade liberalization, what is the combination of trade and environmental policies providing the highest welfare? This thesis addresses these two key questions with an empirical analysis of the North American hog/pork industry.

While the first-best and second-best optimal trade and environmental policy combinations have been identified theoretically (e.g. Krutilla, 1991), empirical studies are necessary since many of the theoretical findings depend on the magnitude of environmental cost (i.e. the value of physical damage) and on supply and demand elasticities of goods produced.

The hog industry is a good case study from an environmental perspective. The hog industry, and the livestock sector in general, are important contributors to pollution, especially water pollution. In the US, it is estimated that the agricultural sector is responsible for 64% and 57% of nonpoint source pollution of rivers and lakes, of which 20% may be attributed to livestock waste (United States Department of Agriculture (USDA) cited in Bouzaher *et al.,* 1993b).

Potential environmental problems from the livestock industry include: eutrophication of surface waters by phosphate emissions, pollution of groundwater by nitrate emissions, contamination by heavy metals, such as cadmium, copper, mercury, lead and zinc originating from concentrated feedstuffs, contamination by pathogenic micro-organisms, and odor nuisance.

Nitrates and phosphates have received the most attention in the literature. Nitrates affect human health: infants under six months of age are susceptible to the potentially lethal blood disorder, methaemoglobinaemia, caused by large amounts of nitrates in drinking water. A link between excessive nitrate levels and stomach cancer is a more controversial issue.

Contamination by phosphates causes eutrophication of inland waters which is associated with increased algae and aquatic plant growth, oxygen depletion, pH variability, and changes in plant species quality and food-chain effects. Certain blue-green algae in eutrophied waters form potent toxins, cause taste and odor problems, and interfere with drinking water treatment. Growth of larger plant forms limit the usefulness of inland waters for recreational and navigational purposes, and decreases the potential for commercial and sport fishing (Sharpley *et al.*, 1994).

Unfortunately, the economic costs associated with these environmental damages have not been assessed. The widespread nature of the problem requires information regarding all categories of damages (health risks, reduction of commercial and recreational fishing, etc.) and their costs for different regions. Hence, these costs are not incorporated into supply decisions of livestock producers, creating a market failure (market prices differ from social costs which equal private and environmental costs). Since the total costs associated with nitrate and phosphate pollution in North America would have to be included in a measure of social welfare, this thesis measures market rather than social welfare. Market welfare is defined as the Marshallian measures of producer and consumer surpluses plus government payments.

To correct the market's failure to incorporate environmental costs, policies and regulations or "command and control" approaches (such as standards, bans, and restrictions on input use), and incentive-based mechanisms (such as taxes, subsidies, and marketable permits) are implemented. Regulations are chiefly used in the livestock sector to restrict pollution because many environmental problems associated with agricultural production are nonpoint source pollution problems; to implement an incentive-based mechanism like taxation, policymakers must first identify the polluter and determine the extent of the polluter's responsibility. Examples of environmental regulations in food and agriculture include: restrictions on land use, quotas on the production and application of manure, restrictions on the number of animals per hectare or size of livestock operations, and restrictions on dumping pollutants into surface or groundwater supplies (Krissoff *et al.,* 1996). Another type of policy, identified as Best Management Practices, specifies tillage and crop rotation practices, terrace, grassed waterways, fertilizer, and water and pesticide applications.

While environmental policies targeted to the livestock sector have used "command and control" instruments, Canadian income stabilization policies designed to attenuate risks incurred from price variations have used subsidies as policy instruments. These support programs are not necessarily resource-neutral: environmental effects can be amplified when public policies raise output prices above the market level. Furthermore, these federal and provincial programs are targeted when countervailing duties are levied by the United States against Canadian hog exports. Numerous government programs were judged countervailable on the basis of the US "specificity test" in the case brought by the United States against Canadian hog and pork exports in 1984 and against Canadian exports of fresh, chilled, and frozen pork in 1989. However, payments under the federal Agricultural Stabilization Act (ASA) and the Quebec Farm Income Stabilization Insurance Program (QFISIP) accounted for 80% of the total calculated subsidy in the 1984 investigation. Further, payments from the National Tripartite Stabilization (NTS) program, which replaced ASA for hogs, and from the QFISIP accounted for nearly 90% of the total calculated subsidy in the 1989 investigation (Moschini and Meilke, 1993). This thesis studies the economic and environmental impacts of the removal of these programs and consequently of the elimination of countervailing duties levied against Canadian hog and pork exports by the US.

Only one trade barrier remains: a nontariff barrier banning live US hog imports in Canada to prevent the spread of pseudorabies. Pseudorabies is a viral disease affecting most warm-blooded mammals except people, for which there is no vaccine or treatment. Swine are its natural hosts. The disease has not occurred in Canada, though sporadic outbreaks have occured in the US since 1931. These outbreaks kill piglets and cause reproductive problems in sows. Pseudorabies can be introduced into a healthy herd of swine by an infected carrier animal that shows no signs of illness, by contact between infected and susceptible pigs, contaminated clothing, or commonly by meat products (Agriculture Canada, 1988). Removal of the ban on US imports of live hogs in Canada is simulated but the potential trade related externalities associated with pseudorabies are not analyzed in this thesis.

To summarize, the hog/pork sector is an expanding industry in an open international market. Its rapid growth triggers environmental concerns from local communities with "command and control" regulations as a consequence; an increasing demand for estimating economic and environmental impacts and trade-offs of new regulations is a result.

Objectives

The first objective of this study is to develop a framework to measure the impact of trade, agricultural and environmental policies on water quality. Water quality is measured by the levels of two environmental indicators, nitrates and phosphates.

The second objective is to assess trade and market welfare impacts of various combinations of agricultural, environmental and trade policies.

Organization of the Thesis

Chapter II reviews the literature on trade, environmental and hog/pork models. Chapter III describes the conceptual model used in this thesis for linking trade and environmental variables. Chapters IV and V present all aspects of the economic and environmental models, including data transformations, sources, validation results and possible modelling extensions. Chapter VI analyzes the impacts of policy scenarios on water quality, welfare, trade patterns, slaughter amounts and hog inventories (i.e. hog numbers). Chapter VII discusses conclusions and their policy implications. The economic model is presented in Appendix.

CHAPTER II - LITERATURE REVIEW

A survey of literature on trade and the environment by Dean (1992) presents an overview of the main points of debate. Almost 20 years ago, several studies were conducted on the impact of environmental policies on the comparative advantages and relocation of production. The pros and cons of harmonized international standards were discussed and alternative policies (like subsidies and countervailing duties) capable of alleviating changes in comparative advantages were scrutinized. The analysis was extended to include transboundary pollution and to the trade of hazardous substances. [1]

In 1992, virtually no analytical work existed on the impact of removal of trade barriers on environmental degradation (Dean, 1992). To date, studies accounting for changes in soil and water quality due to policy reform often lack multiple-country coverage because the environmental and economic effects of policy reform are region-specific and depend critically on site-specific land, climate, and farm structure characteristics (Krissoff *et al.*, 1996). Linkages between trade and environmental components have not yet been made for the hog/pork industry. The five most essential elements in this study: trade, multi-stage modelling of pork production (from the sow herd to pork production), government stabilization programs,

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[1] Subsequently, the literature was reviewed by Jaffe *et al.* (1995).

environmental policy and the resulting environmental degradation have not been adequately linked. Hence, the literature is reviewed for each component separately: trade models, models of the agricultural sector incorporating the environmental dimension and models of the hog/pork sector. Trade models are discussed in the next section.

Trade Studies with Environmental Variables

Recently, the impact of trade liberalization on environmental quality has been assessed within a general equilibrium framework. Copeland and Taylor (1995) developed different theoretical models involving North-South trade, and Espinosa and Smith (1995), Beghin, Roland-Holst and van der Mensbrugghe (1995) and Perroni and Wigle (1994) used Computable General Equilibrium (CGE) models to obtain empirical results. The latter authors use an environmental model including damage and valuation functions where the elasticity of damage with respect to emissions is assumed to be greater than unity. They recognize that these elasticities are likely to be different for specific types of emissions and vary across regions, to reflect differences in assimilative capacity.

These differences are best accounted for within a partial equilibrium framework. Partial equilibrium results are more relevant for policymakers involved in waste management since environmental policies are specific to the livestock sector and trade policies, such as tariffs, are set commodity by commodity.

Many studies use partial equilibrium models of the agricultural sector to assess the production, consumption, trade and market welfare consequences of eliminating agricultural policies following trade liberalization. Studies, which are either static or dynamic, include different numbers of regions, commodities, and agricultural policies.

Hester *et al.* (1993) is the only empirical trade study containing both trade and environmental policies related to the pork sector (among other sectors). Their most interesting contribution is the comparison of the effects of modifications of agricultural with environmental policies. These authors compare the effects of trade liberalization for agricultural policies with the effect of environmental policy on world prices and trade volumes of various commodities including pork. The environmental policy modelled consists of a 1% reduction in livestock density for specific livestock industries of the European Community where intensive livestock production has caused serious adverse environmental effects. As part of the recent Common Agricultural Policy reforms, limits were imposed on stocking densities. A 1% reduction in pork density in Belgium/Luxembourg, Denmark, France, Germany and the Netherlands induced an estimated decrease of 0.4% in pork production, an estimated decrease of 8.9% in net exports and an estimated increase of 0.4% in price. The Static World Policy Simulation Model (SWOPSIM), a synthetic model integrating parameters such as elasticities obtained from the literature, was used. This model incorporates data from many countries and many commodities.

SWOPSIM includes the grain sector, an asset, since the elimination of its policies might have a greater effect to the pork sector, than the elimination of direct income support policies (Shagam, 1990). In the model, the feed sector is linked to the pork sector by incorporating a derived demand for feed by the livestock sector in the demand for feed. The price of feed is also an important variable in the supply of livestock.

SWOPSIM incorporates policies even though it is not a policy specific model where, for example, all formulas for price stabilization are endogenized. A policy is represented as a fixed difference between the traded price and the domestic incentive price. The policy price wedge data are obtained from the Economic Research Service's calculations of producer and consumer subsidy equivalents.

Hartman (1993) uses an adaptation of SWOPSIM, the Trade and Environmental Policy Simulation model (TEPSIM), to estimate the trade and welfare effects of nitrogen taxes in the European Community. Her study includes both agricultural output (e.g. pork) and input markets. The results show that a level of taxation of 25%, 50%, 100% and 200% would increase the European Community's net exports of pork by 1%, 2.6%, 4.4% and 7% respectively.

Bohman and Lindsey (1997) model the North American sheep and lamb markets to explore the market and non market consequences of environmental regulations and trade liberalization. They conclude that producers can gain from regulation enforcement by shifting a significant portion of the cost of regulation to consumers and nonmarket effects are unlikely to reverse the sign of market gains or losses.

Hartman (1993), Hester *et al.* (1993) and Bohman and Lindsey (1997) do not attempt to assess the environmentally optimal level of reduction in livestock density, which is the major drawback of all agricultural trade liberalization studies. Consequently, the effects of reforms on welfare have not yet been fully evaluated (Anderson, 1991).

Three other studies focusing on the hog and/or pork sector and incorporating trade components are reviewed. Although they do not consider environmental policies and degradation, these variables could be added.

Hog/Pork Studies with Trade Variables

Wahl *et al.* (1992) measured the effects of gradual liberalization in Japanese pork import policies by using an annual multimarket econometric livestock sector model. This model contains three blocks corresponding to pork, beef, and poultry markets. The blocks are linked by a retail meat demand system that includes pork, Wagyu beef, import-quality beef, poultry, and fish expenditures. Wahl *et al.* (1992) use an econometric model which is not as convenient as a programming model to impose constraints and offer various technological choices. In fact, most studies incorporating the costs of controlling nitrate pollution use linear programming models (Hanley, 1990).

For example, Hahn (1993) built a static mathematical programming model for North American trade of animal products which can be linked to a grain model if necessary. Hogs and pork, among other livestock commodities, are included. A dynamic model is preferable because it shows the adjustment pattern whereas a static model only predicts market equilibrium. The fact that tariffs and subsidies are not necessarily phased out in equal instalments, and different elimination schedules induce different costs can be incorporated in a dynamic model. In static models, stocks are not modelled and assumed to be unchanged. This is a serious weakness, since, in hog production, policy variables first affect breeding stocks which determine hog marketings nine to ten months later.

Spinelli (1991) modelled the Canadian and US hog/pork sector with a multi-stage dynamic mathematical programming model. He modelled countervailing duties imposed on Canadian exports to the US, but did not include government programs, price expectations and risk, and the forecasting power of his model has suffered because of this. These programs must be included because they are not necessarily resource neutral and can change environmental impacts. Spinelli divided Canada into Western and Eastern regions, which would capture the reallocation of production in Canada following modification of the Western Grain Stabilization Act. It would not, however, reflect the effects of provincial stabilization programs or provincial environmental legislations.

Economic studies modelling the livestock sector and incorporating environmental variables are reviewed in the next section.

Environmental Studies

Heady and Vocke (1992) use a linear programming model of the US to analyze a set of policies designed to alter current agricultural practices to reduce US agriculture's impact on the environment. The endogenous crop production sector includes alternative production activities for grain sorghum, sorghum silage, barley, corn, corn silage, cotton, legume and non-legume hay, oats, soybeans, sugar beets, and wheat. Endogenous livestock production activities in the model are defined for hogs, beef cows, beef feeding, and dairy. The advantage of linear programming is that it can include environmental constraints. The authors use a nitrogen balance equation where all nitrogen produced in wastes is applied on the land. The first scenario restrains nitrogen use to a maximum of 50 pounds per acre while the second scenario requires the construction of runoff control facilities at additional costs.

Saygideger and Heady (cited in Heady and Vocke, 1992) studied trade-offs between soil erosion control and costs of producing output. Their objective function minimizes production and transportation costs and total soil loss. Two problems are associated with their approach. First, minimizing pollution levels below a threshold might be an overkill and second, the researcher must arbitrarily assign relative weights to each objective, which has a significant impact on the solution.

Abrams and Barr (1974) studied the least cost way of achieving target nitrogen emissions from inorganic sources rather than from organic and inorganic sources. They used a spatial, linear programming model of the US cattle-feed complex and an environmental model. They did not, however, study the impact of limiting organic wastes on fields. A multiple regression model was used to relate nitrate levels to fertilizer usage, followed by addition of the ideal fertilizer using environmental constraints on regional crop production in the programming model. According to the authors, this procedure should be regarded as exploratory. Variables such as rainfall, soil type, slope of cultivated land, drainage, crop, timing of application, location of the land within the watershed, and level of application per acre cropped were not used.

Moon *et al.* (1994) conducted a pilot study to determine the utility of an information system to support animal waste management decisions for the Fraser Valley. Their primary goal was to define the probable magnitude of livestock contribution to groundwater nitrogen. They partitioned existing soil nitrogen and added manure nitrogen to inorganic additions, mineralized nitrogen, volatilization, denitrification, crop uptake, and deep losses, choosing to impose a maximum concentration of nitrogen in leachate reaching groundwater. Although economic assessment was conducted to determine the impact of alternative land use and manure transport restrictions, it was limited to an enterprise budget, ignoring the demand side, slaughtering, processing, and trade activities. These variables can be simulated with an economic model.

Therefore, it is necessary to link economic and environmental models to fully integrate economic and environmental components. This integrated systems approach has been applied at the farm, watershed and regional level (Bouzaher *et al.,* 1993a). The three most relevant studies for this thesis used the Erosion Productivity Impact Calculator (EPIC) or one of its variants. Lakshminarayan *et al.* (1996) evaluated resource neutralities of two stabilization programs and their associated risk reductions emphasizing land use and soil degradation in Western Canada. The objective of a second project was to determine technologies, management methods, policies, and institutional settings reducing the negative impacts of the dairy industry on the environment and at the same time resulting in a competitive industry (Osei *et al.,* 1995). Research on dairy pollution in Erath County, Texas, served as the baseline study. The economic model distinguishes between small, medium and large herd sizes because of the economies of size and scale in milk production and waste handling systems. A linear programming model is used to capture the complex interrelationships among policy, economic, nutrient and odor parameters at the farm level. The model identifies both farm-level economic impacts of alternative policies and farm level nutrient and odor emissions.

Mapp *et al.* (1994) compared the quantitative distributions of nitrates and pesticides lost in runoff and percolation for different regions and soils under alternative water quality policies such as per-acre restrictions and total nitrogen restrictions. They linked an economic mathematical programming model to a variant of EPIC, incorporating a pesticide subroutine and MODFLOW (an aquifer model which determines the amount of drawdown and water levels in the aquifer).

The framework of the three studies described previously is comparable to the approach chosen in this thesis, which is explained in the conceptual framework in chapter III.

CHAPTER III - THE CONCEPTUAL MODEL

To assess the impacts of environmental, trade and agricultural policies on water quality, trade patterns and market welfare, this research links a model of the North American hog/pork sector to an environmental model. Modelling the relationships between local environmental impacts from agricultural production and international policies poses a severe challenge. Trade liberalization affects prices and has widespread effects on production and consumption in more than one country. In contrast, environmental impacts of changes in output depend on local environmental conditions. The conceptual model, presented in the next section, shows how these scale differences are dealt with in this thesis.

Description of the Conceptual Model

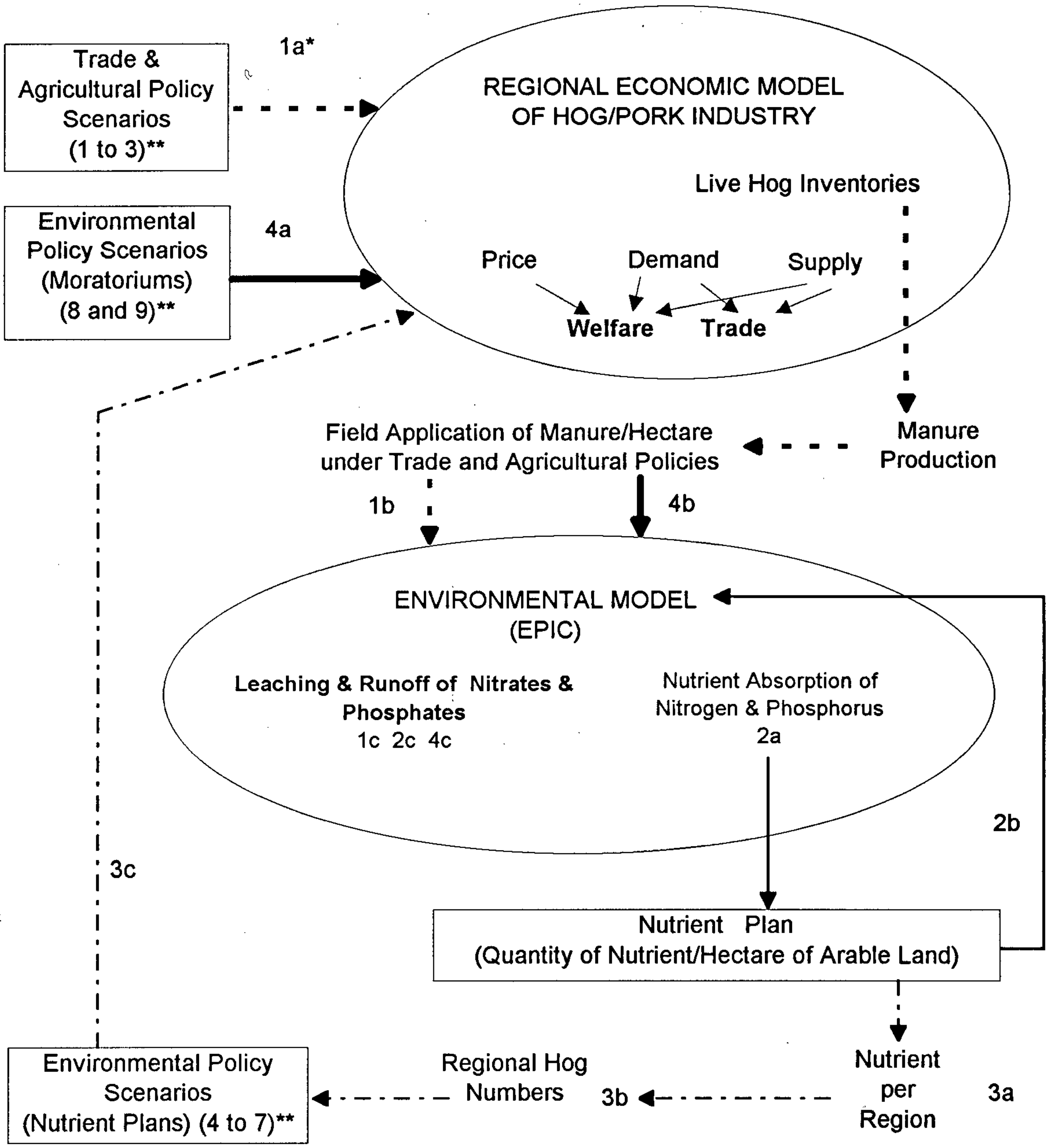
Objectives of this study are achieved by integrating an environmental model with an economic model using a conceptual framework (Figure 1). Outputs of the models are circled, while policy scenarios, which are compared to a base scenario, are in rectangles. Output variables of most interest to reach the objectives of this thesis are in bold type.

The economic model is a spatial mathematical programming model of US and Canadian swine industries. The model solves for equilibrium quantities such that markets clear at all levels. Important output variables are live hog inventories, quantities marketed and traded, and prices of hogs and pork in the US and Canada. These variables are used to calculate regional market welfare. Recall that market welfare is defined as the Marshallian measures of producer and consumer surpluses plus government payments.

The Erosion Productivity Impact Calculator (EPIC) is the environmental model used in concert with the economic model. It is a field-scale model simulating 158 output variables. This thesis focuses on leaching and runoff of nitrates, runoff of phosphates and nutrient absorption of nitrogen and phosphorus.

Procedures to measure impacts of trade and agricultural policies on water quality, welfare, and trade, can be followed from 1a to 1c and the impacts of nutrient management plans on water quality are depicted in steps 2a to 2c. Under these plans, land application of manure must not exceed crop agronomic requirements. Procedures to assess the impact of nutrient management plans on welfare and trade can be traced from 3a to 3c. The impact of a moratorium prohibiting increases above the 1987 hog inventory level is shown from 4a to 4c. In the following sections, each of these four procedures measuring different impacts, is discussed in more detail.

Figure 1. Conceptual Model



* Numbers (e.g. 1a) refer to the type of policy analyzed. The links between models and other calculations are shown by the arrows.

1a, 1b and 1c: Impact of trade and agricultural policies on water quality, welfare and trade

2a, 2b and 2c: Impact of nutrient management plans on water quality

3a, 3b and 3c: Impact of nutrient management plans on welfare and trade

4a, 4b and 4c: Impact of moratoriums on water quality, welfare and trade

** See Table 1

Impacts of Trade and Agricultural Policies on Water Quality, Welfare, and Trade

Trade and agricultural policies (1a in Figure 1) are incorporated within the economic model which predicts the regional hog inventory from which the regional amount of manure produced can be calculated. In order to use these results in the environmental model, regional results must be translated to per hectare values, the scale of the environmental model. A significant assumption must be made to link the two models. One option is to divide the total amount of manure produced by the area of farmland owned or rented by pork producers to obtain the quantity of manure applied per hectare. This option is not chosen since it is not realistic to assume that the whole land base is used as pointed out by Abdalla *et al.*: "Since most animal manure is costly to transport and usually has low economic value, it often is spread on or near (sic) farm fields" (Abdalla *et al.,* 1995).

An alternative method is selected. In the base scenario, the nitrogen from manure and mineral fertilizer, equalling three times the recommended rate of mineral fertilizer, is applied. According to Ganbazo (1995), the common practice is to apply the recommended amount of fertilizer and add twice as much manure. "Producers continued to apply fertilizer because they had no confidence in the nutrient value of manure. Manure was spread on the land at high rates simply to get rid of it" (Ganbazo, 1995). Hog manure having a lower dry matter content and lower fertilizing value than beef and poultry manure, transportation costs per kilogram of nitrogen to spread hog manure off the farm are higher than the costs to transport poultry or beef manure.

In trade scenarios, the amount of nitrogen is adjusted according to changes in live hog inventories since the amount of manure produced is directly proportional to these inventories. Hence, if inventories increase by 1%, the kilograms of nutrient also increase by 1%. This method assumes that farmers use a constant quantity of land.

The quantity of manure nutrients applied to one hectare is then incorporated into the environmental model with weather, soil and plant data (1b in Figure 1). Like field experiments performed on small plots, model simulations on small areas are indices of natural processes occurring at a larger scale leading to the leaching and runoff of nitrates and phosphates. Thus, changes in production levels, simulated with the economic model, are inputs in the environmental model to compare the impact of different trade and agricultural policy scenarios on water quality (1c in Figure 1).

Raleigh, North Carolina and Pont-Rouge, Quebec are the sites chosen to run the environmental model. Both regions are facing environmental threats from the hog industry. For example, in North Carolina, emergency inspections by 2 state agencies following spillovers[2] found 124 lagoons filled to the brink and

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[2]"After heavy rains last spring, the earth wall of a lagoon burst on June 21, 1995 and sent 22 million gallons of water and pig waste into the new river above Jacksonville, killing 4,000 fish,

526 dangerously overloaded (*The Economist*, September 2-8, 1995). In Quebec, a group of 18 non-governmental organizations registered a complaint with the Environmental Co-operation Commission of the North American Free Trade Agreement (NAFTA), in April 1997, alleging that the Government of Quebec neglected to adhere to environmental norms related to agricultural pollution originating from animal, especially hog, production.

Impacts of Nutrient Management Plans on Water Quality

The optimal quantity of manure needed to meet crop agronomic requirements is determined with the environmental model and nutrient management plans are designed (2a and 2b in Figure 1). The optimal quantity of manure applied is based on the quantity of nitrogen and phosphorus absorbed by crops on a hectare basis. When studying the impact of nutrient management plans on water quality (2c in Figure 1), there is no scaling problem since the only model used is the environmental model. Hence the assessment is on a per hectare basis.

Impact of Nutrient Management Plans on Welfare and Trade

To obtain the maximum regional level of nutrients required for a nutrient management plan, based on crop agronomic requirements (3a in Figure 1), the absorption of nutrients is multiplied by the number of hectares owned or rented by hog

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closing a nearby river to swimmers and boaters, and threatening shellfish beds 15 miles downstream. Five other spills followed." (*The Economist*, September 2-8, 1995 p.24) producers. The regional quantities of nutrients can be translated into a maximum hog inventory i.e. a maximum number of hogs per region (3b in Figure 1) by assuming that manure contains a fixed amount of nutrients every year across regions. When this sustainable inventory level is lower than actual inventories, a constraint, which fixes a maximum inventory level, is inserted into the economic model. Hence the optimal quantity of manure is translated into environmental policies which are incorporated into the economic model and used to calculate their impact on market welfare (3c in Figure 1). Thus, a loop links the economic to environmental and back to the economic model.

Scales of the Environmental and Economic Models

An interest in drafting a methodology to link a large-scale economic model comprising trade with an environmental model motivated the adoption of the procedures described above. If the environmental model were limited to study the impact of nutrient management plans on water quality (2c in Figure 1), scaling problems would be eliminated. The objective would be reached by using the environmental model without the economic component on a per hectare basis. Incorporating the assessment of the impact of international trade policy on water quality requires making strong, but necessary, assumptions.

Furthermore, the linkage from the environmental to the economic model could be avoided. Environmental policies inserted into the economic model could be designed without using the environmental model, thus eluding scaling problems. For example, the moratorium scenarios (4a in Figure 1) are not founded on environmental endowments. The moratoriums prohibit increases above the 1987 hog inventory level, 1987 being the first year of the simulation period. The maximum level does not take account of simulation results on the land assimilative capacity provided by the environmental model. Hence the box including these two policy scenarios is not integrated in the arrow linking the environmental to the economic model (4a in Figure 1). Although the procedure is seen as exploratory, the use of EPIC to design nutrient plans for four of the six environmental scenarios described in the next section is seen as a contribution to an area of ecological economics needing further research.

Trade and Environmental Scenarios

The four types of linkages identified in Figure 1 incorporate nine policy scenarios: three trade liberalization scenarios and six environmental policy scenarios (2 moratoriums and 4 nutrient plans). Liberalization scenarios encompass important liberalization endeavors while environmental policy scenarios address different levels of policy harmonization taking into account current policies. The baseline depicts the trade policies in force during the study period and the common practice regarding waste management. Characteristics of the baseline and the nine scenarios are found in Table 1.[3]

[3] Detailed results from an additional scenario with a constant exchange rate equal to 1 are not reported since this situation is not expected to occur in the near future. It would induce decreases in Canadian live hog and pork exports to the U.S. of 16% and 22% respectively. These changes are in accordance with the 20% increase in value of the Canadian dollar.

Table 1 Characteristics of the Baseline and Nine Scenarios

Scenarios						
	Nontariff barrier	Stabi-lization payment	Coun-tervail	% of 1987 Quebec inven-tory level	% Increase in non feed costs in 5 regions (other than Quebec)	% of 1987 inven-tory level all regions
B	Yes	Yes	Pork & Hog	Any level	No	Any level
1	Yes	Yes	Hog	Any level	No	Any level
2	Yes	No	No	Any level	No	Any level
3	No	No	No	Any level	No	Any level
4	Yes	Yes	Pork & Hog	96.5	50	Any level
5	Yes	Yes	Yes	96.5	No	Any level
6	Yes	Yes	Pork & Hog	35	50	Any level
7	Yes	Yes	Yes	35	No	Any level
8	Yes	Yes	Pork & Hog	100	No	100
9	No	No	No	100	No	100

B:Baseline

In the first category (1a in Figure 1), liberalization is increased by steps from scenario 1 to 3. First, the pork countervailing duty is removed, followed by the hog countervailing duty and stabilization programs. Finally, the ban on US live hog imports in Canada imposed because of the threat of the spread of pseudorabies is eliminated.

Scenarios 4 to 9 are environmental scenarios chosen to cover different policy harmonizations. Harmonization of policies is an important issue to consider when implementing environmental policies within an international context. Environmental policies vary across regions mainly because of variations in preferences and endowments of environmental quality (through assimilative capacity). Thus, varying demand and supply of environmental quality suggests different optimal levels of environmental protection. There is a perceived danger that differences in the stringency of policies or in their implementation, however, may create pollution havens where pollution-intensive firms can relocate. This is an argument for policy harmonization, where the distinction must be made between the harmonization of objectives and the instruments used to reach those objectives. Two regions can have the same objective e.g. limit the amount of nitrates in runoff to 6 mg/L and use different policy instruments to attain this objective. One region can require the certification of nutrient management plans while the other region can limit the hog numbers per hectare.

Scenarios 4 and 6 simulate multilateral implementations of nutrient management plans using policy instruments which are specific to regional needs, while scenarios 5 and 7 simulate the unilateral implementation of nutrient plans in Quebec (3c in Figure 1). The design of scenarios 4 to 7 required a number of calculations which are exposed in next section.

Scenarios 8 and 9 harmonize policy instruments multilaterally by simulating the implementation of a moratorium under actual and free trade conditions (scenarios 8 and 9, respectively). A moratorium on the 1987 inventory levels is simulated in scenario 8. Moratoriums have been used for many years in Quebec and were recently implemented in North Carolina.[4] Moratoriums are not economically and environmentally optimal because they do not allow supply to respond to market prices and they are not designed according to assimilative capacity but they are easier to monitor than nutrient management plans. It is almost impossible for inspectors to verify that all land necessary to respect the plans is utilized for manure applications. On the other hand, regional data on inventory and marketing are published in Canada and the US allowing all interested parties to assess this policy's success. In this context, moratoriums can be practical though not optimal.

Scenario 9 combines trade and environmental policies. The moratorium on 1987 inventories is simulated under free trade

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[4]See the section on policy implications for more details.

conditions to take into account potential opposing effects of trade and environmental policy on inventory changes.

Design of Scenarios 4 to 7

Scenarios 4 and 6, which are identified in Figure 1 as nutrient plans, use EPIC simulation results on the absorption of nutrients. The objectives of the nutrient plans are harmonized, but different policy instruments are implemented depending on whether farmers can expand the land base for manure applications. Two types of environmental instruments are applied: 1) restrictions on inventories when the land base is insufficient, and 2) increases in transportation costs to spread manure on larger areas.

To determine which policy instrument is appropriate for each region, the ecosystem support capacity for hogs i.e. the maximum inventories must be estimated. The support capacity is assessed by calculating the maximum amounts of nutrients which can be applied on land and its corresponding hog inventory.

First, the maximum amounts of nutrients are obtained by multiplying the consumption of nutrient per crop per hectare, by the number of hectares owned or rented by hog producers (Table 2).

Table 2 Kilograms of Nitrogen and Phosphorus Permissible under Two Nutrient Management Plans in the Southeast and in Quebec Using EPIC Crop Absorption Rates

Region and Crop	Kilograms of Nitrogen under the Nitrogen Plan		Kilograms of Phosphorus under the Phosphorus Plan	
	Per Hectare	Per Region	Per Hectare	Per Region
	Kg	Million Kg	Kg	Million Kg
Southeast (Forage)	73	207.45	20	56.84
Quebec (Corn)	106	15	22	3.11
Quebec (Forage)	84	11.89	30	4.25

[1] Species which compose forage in North Carolina are different from those that compose forage in Quebec.

To translate regional amounts of nutrients into regional hog numbers (3b in Figure 1), the total quantity of a nutrient must be divided by the quantity of nutrients produced by one animal. Choices for the concentration of nitrogen and phosphorus in manure is of primary importance. One can consider the fertilizing value of manure at different stages of the manure treatment, which can be measured before storage or after storage, but before land application. The value of nutrients available to crops, after soil incorporation losses, should also be taken into account. This can be a significant value since, in North Carolina, 70% and 20% of the nitrogen is lost following anaerobic lagoon treatment and manure storage respectively (personal communication with James C. Barker, Professor and Extension Specialist, Biological and Agricultural Engineering, North Carolina State University). In Quebec, the loss is around

40% (Gouvernement du Québec, 1995).

Losses to the atmosphere should not be ignored since ammonium emissions are converted into nitrates contributing to acid rain which returns nitrogen to the land. One way to account for air and water quality is to measure nutrient content in manure before volatilization to the atmosphere and soil incorporation losses. The impact assessment of environmental policy scenarios 4 to 7 on trade patterns and welfare (3a to 3c in Figure 1) is based on ecosystem assimilative capacity rather than on soil assimilative capacity.

To analyze the impact of nutrient management plans on water quality (2b and 2c in Figure 1) the ratio of nitrogen to phosphorus is not the same as the one used to find sustainable inventory levels. The former ratio is found after volatilization and treatment, following storage of manure, since the focus here is only on the impacts of land applications on water quality; not on total air and water quality. Since the proportion of nitrogen volatilized which returns from the atmosphere to the land, and the location at which nitrogen returns after being carried by air currents are unknown, that portion of nitrogen is ignored when examining impacts of nutrient management plans on water quality.

Since nutrient levels in manure are fairly comparable in North America, a hog at the finishing stage is assumed to produce 10.44 kg of nitrogen and 5.22 kg of phosphorus annually, which is the nutrient content before losses (Gouvernement du

Québec, 1995).[5] Maximum nitrogen and phosphorus levels are divided by 10.44 and 5.22 respectively to obtain the maximum hog inventory levels. Maximum inventories are converted to percentages of 1987 levels; the year 1987 is chosen since it is the start of the simulation period. Results in Quebec and in the Southeast are shown in Table 3.

Table 3 Hog Inventory Permissible under Two Nutrient Management Plans in the Southeast and in Quebec

Region and Crop	Nitrogen Plan		Phosphorus Plan	
	Maximum Hogs Numbers [1]	% 1987 Hog Numbers[2]	Maximum Hog Numbers [1]	% 1987 Hog Numbers [2]
	Million Head	%	Million Head	%
Southeast (Forage)	11.16	295	5.23	138
Quebec (Corn)	0.8	**96.5**	0.29	**35**
Quebec (Forage)	0.64	77.2	0.39	47

[1] Hogs at the finishing stage
[2] 1987 simulated levels

Since Quebec inventories already exceed the land capacity, restrictions on inventories are imposed in that province. According to results shown in Table 3, producers must reduce hog

[5]A boar and sow, with piglets, produce 22.1 kg of nitrogen and 15.14 kg of phosphorus and the herd is assumed to be composed of 48% piglets, 38% hogs at the finishing stage and 14% sows and boars.

marketings to 0.8 and 0.64 million head (for corn and forage, respectively) to respect the nitrogen plan, corresponding to 96.5% and 77.2% of the 1987 levels. The phosphorus plan is more constraining and requires reductions to 35% and 47% (corn and forage, respectively) of the 1987 levels.

The environmental scenarios chosen, are the least and the most restrictive. Scenarios 4 and 6 constrain inventories to 96.5% and 35% of 1987 levels (in bold type in Table 3). Results from restricting inventory levels to 77.2% and 47% of 1987 inventory levels are expected to fall in between the most and least restrictive inventory restrictions.

Conclusions on sustainable hog inventory levels depend on assumptions made concerning the number of hectares available for land applications of manure. In fact, if land on which wheat and small grains are cultivated is added to land owned or rented by Quebec hog producers, the number of hectares jumps from 141,520 to 443,240 without a need to restrict inventory. These areas, however, have to be shared with other livestock producers and it is beyond the scope of this thesis to include manure production from other species.

Nevertheless, information from different sources confirm that the land base in Quebec is insufficient to dispose of all the manure produced. Each year, there is an excess of 3.6 million cubic meters of manure for which land is unavailable close to production units (Gouvernement du Québec, 1996). Also, the 1995-1996 report from the Auditor General states that there is a surplus of 7 million cubic meters of manure applied on land[6].

In the Southeast, however, land capacity is sufficient and increases in costs to spread manure on larger areas are simulated. Increases in costs are also incorporated in the Midwest, in Western Canada, in Ontario and in the Atlantic provinces. On average, 1,684 gallons of slurry are assumed to be produced per head per year.[7] In Indiana, "a custom service hauls slurry up to three-quarters of a mile for a price of one cent per gallon (Jones; Foster). If slurry is spread in a concentric circle around the hog house, three-quarters of a mile represents over one thousand acres (1,130 ac)." (Roka, 1993). At one cent a gallon, the annual cost is US$16.84 or US$4.21 per quarter per head. This cost is entered in scenarios 4 and 6 simulated with the economic model, which is presented in chapter IV.

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[6]Rapport du Vérificateur général à l'Assemblée nationale pour l'année 1995-1996. Tome I, Chapitre 2, Aide financière offerte aux producteurs agricoles. Etude conduite auprès du ministère de l'Agriculture, des Pêcheries et de l'Alimentation, de la Régie des assurances agricoles du Québec et de la Société de financement agricole.

[7]A market hog and sow with piglets produce respectively 2.9 and 8.5 m^3 per year of slurry (Gouvernement du Quebec, 1995). Spinelli (1991), states that the inventory is composed of 38% market hogs and 62% sows and piglets. The weighted average of slurry per head converted into gallons per year equals 1683.96.

CHAPTER IV - THE ECONOMIC MODEL

The economic model is an adaptation of a spatial mathematical programming model of US and Canadian swine industries (Spinelli, 1991). It is a multi-stage partial equilibrium model which is dynamic, regional and incorporates a risk variable; features described following the presentation of the objective function, feed costs, pork demand and output variables. Data values and validation of results are shown thereafter. The model, including equations and the objective function, is described in appendix A.

The Objective Function

The model's objective function maximizes market welfare defined as the Marshallian measures of producer and consumer surpluses plus government payments. The demand function is uncompensated since pork is a small portion of total consumer expenditures and major shifts in pork prices have small effects on the cost of living.

The objective function does not maximize social welfare which includes the economic benefits derived from environmental quality, because economic values for decreased nitrate and phosphate levels in North America do not exist. Hanley (1990) explains:

> "...economists seem to have neglected benefit estimation for nitrate pollution control: much more work is needed in this area. Alternatively, we might judge benefit estimation

to be too difficult, and seek efficient ways of achieving politically-determined target nitrate levels at the lowest possible resource cost." (Hanley, 1990).

Hence, the approach chosen in this thesis is to maximize market, rather than social welfare. The objective is to maximize the area under each region's pork demand function, adding government payments and subtracting all costs which are: a) fixed or variable costs for producing pigs and hogs, for each age cohort and each production region (including actual abatement costs), b) transportation costs for moving feeder pigs between production regions, c) all slaughter, processing, storage, and transportation costs incurred while preparing and distributing slaughtered and processed pork carcasses, d) a wholesale-retail marketing margin, e) countervailing duties which are translated into an equivalent cost increase for transporting products from Canada, and f) risk associated with price variability.

Feed Costs and Pork Demand as Driving Forces of the Model

Feed costs and the demand for pork are the driving forces of the model. Feed costs influence the size of regional hog herds whose dynamics are driven by the size of the breeding herd. Feed prices are exogenous and hence do not allow changes in animal production to affect grain demand or prices.

Demand for pork is represented by an aggregate quarterly retail demand function for composite pork products comprising different cuts of pork. For example, the US seasonal retail pork demand equation obtained by Spinelli (1991), for the first quarter, from a linear regression with ordinary least squares (OLS) is:

$$PCPC_t = 15.421 - 0.058\ RPP_t + 0.022\ BRP_t + 0.049\ CRP_t + 0.077\ PINC_t$$

PCPC = per capita pork consumption
RPP = pork retail price
BRP = beef retail price
CRP = chicken retail price
PINC = personal per capita income
t = quarter t

Regression parameters used by Spinelli (1991) are used with updated data for independent variables. Parameters for the US seasonal retail pork demand equation are assumed to apply to all regions. A lack of consistent definitions of retail weight equivalents for pork between Canada and the US makes this assumption necessary. The US retail prices are used for all regions and regional data on personal per capita income differentiate the demand functions. Hence, each region has its demand function and price elasticity since the slope parameter is multiplied by regional average endogenous[8] hog prices over regional average quantities. As a point of reference, the pork price elasticity obtained by Spinelli (1991) using average US price and quantity is -0.768.

Output Variables

The output variables are: the number of animals in the

[8]solved by the model

herd, the actual capital and incremental changes in capital at the farm and SPS levels, the number of hogs marketed, the weight of live animals in farm and SPS regions, the amount of meat produced and in storage, and the demand for retail pork. The number of breeding animals transferred from one production region to another, and the amount of meat shipped from the SPS regions are also simulated.

Important Features of the Model

Dynamics

Dynamics are important aspects of the model's equations. The number of piglets is a function of the breeding herd from the previous period, multiplied by the birth rate, added to the net transfer of piglets across regions. The number of finishers depends on the previous period, and is a function of the number of piglets that survive the weaning stage combined with the net transfer of piglets from other regions. The number of animals in the breeding stock also depends on the previous period, and is a function of breeding inventory and number of surviving finishers, minus the number of marketed animals, plus net transfers across regions. The number of animals culled from the breeding stock is a fixed proportion of the total number of animals entering the stock in the previous quarter.

The model is constrained such that the quantity of pork produced in a SPS region, plus imports, minus quantities shipped to consumptive regions, the military sector, US territories, and export markets, must be larger than the quantity added to storage from the last quarter.

Dynamics also play a role in the replacement of durable assets (buildings and equipment) at the farm and slaughtering levels. The replacement of capital, combined with the undepreciated portion of capital from the last quarter must be greater or equal to the capital available for production.

Regionality

Regionality is a main feature of the model. Production regions are delineated according to prevailing cultural practices in raising hogs and by the amount of feeds produced in each region. Two producing regions exist in the US: the Midwest and the Southeast (comprising North Carolina) and four US SPS regions: East, South, Midwest and Western US. The US demand regions are the same as the SPS regions. In Canada, four production, SPS and demand regions exist: Western Canada, Ontario, Quebec, and the Atlantic provinces.

A central city is chosen for each region (Table 4) to calculate the distances over which traded goods are transported (with corresponding costs). The US regional breakdown is consistent with information provided by the Cooperative Extension Service of Iowa State University (1992) while the Canadian regional breakdown is based on discussions with regional experts.

Table 4 Production, Slaughter, Demand Regions and their Centers

Regions	Central City	Province or State
	Hog Production Level	
Southeast	Charlotte	North Carolina
Midwest	Dubuque	Iowa
Atlantic	Edmunston	New-Brunswick
Quebec	St-Hyacinthe	Quebec
Ontario	Stratford	Ontario
Western Canada	Edmonton	Alberta
	Slaughter, Processing, Storage Level	
East	Philadelphia	Pensylvannia
South	Raleigh	North Carolina
Midwest	Des Moines	Iowa
West	Los Angeles	California
Atlantic	Moncton	New Brunswick
Quebec	Montreal	Quebec
Ontario	Burlington	Ontario
Western Canada	Edmonton	Alberta
	Demand Level	
East	New York City	New York
South	Atlanta	Georgia
Midwest	Chicago	Illinois
West	Sacramento	California
Atlantic	Halifax	Nova Scotia
Quebec	Montreal	Quebec
Ontario	Toronto	Ontario
Western Canada	Edmonton	Alberta

The three types of economic agents, farmers, processors and retailers, act in two vertically related sectors: hogs and pork. Live hogs from each production region can be delivered to the local processing sector or exported to other slaughter, processing, and storage (SPS) regions domestically or abroad. US live hogs, however, cannot be exported to Canada under the baseline because of the threat of the spread of pseudorabies. The SPS sector buys live hogs from the primary sector and sells pork to retailers at home or abroad.

Incorporation of Risk

Risk is a significant addition to Spinelli's model which assumed that producers have a perfect foresight of market prices. After considering previous supply response studies, an adaptive expectations framework is chosen, which is seen as a first attempt to model expectations.[9] Within this framework, economic agents base their expectations on prevailing prices when they make their decisions. Farmers make decisions about hog breeding three quarters before the hogs are ready for slaughter, since the gestation period is four months and the finishing process takes five to six months. Agents at the slaughter, processing, storage and retailer levels, make decisions in the same quarter in which the activity takes place.

[9] Martin and Goddard (1987) discuss specifications of the expectation process.

In this thesis, hog producers are assumed to be risk averse, based on findings of Legault (1995), who showed that 81% of Quebec hog producers are risk averse, 8% risk neutral and 11% risk loving, at an investment level of CDN$150,000. Furthermore, Wilson and Eidman (cited in Legault, 1995) found that 44% of US swine producers are risk averse, 34% are risk neutral and 22% are risk preferring. Also, the assumption is made that market risk has a negative impact on investment decisions.[10] Incorporating risk into dynamic programming models, contributes to a research area that needs to be expanded (Krautkraemer *et al.* 1992):

> "Most previous stochastic dynamic programming (DP) applications have assumed that decision makers are risk neutral; however, risk permeates both intra-year and inter-year relationships in most DP problems... More research on risk averse DP formulations is needed" (Krautkraemer *et al.,* 1992).

In the literature, risk is measured by revenue, price, or yield variability (variance, standard deviation or coefficient of variation). In this study, the proxy for risk, associated with price variability of hogs, is the standard deviation of the endogenous quarterly market prices for the 1981-1986 period.

First, the model is applied to the 1976-1980 period to

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[10] It is common to assume that price uncertainty induces a decrease in investment and output, although Robinson argues that it triggers an increase (cited in Spriggs and van Kooten, 1988): "a substantial part of investment in agriculture occurs in years of high prices since such years provide both the capacity to invest and the incentive, partly because farmers are notorious tax avoiders." (Robinson cited in Spriggs and van Kooten, 1988)

estimate the standard deviation of market prices, the proxy for the expected risk in the following period: 1981-1986. The model is then validated with the 1981-1986 quarterly data including the expected risk. The risk aversion coefficient and the response coefficient to stabilization payments are estimated over the 1981-1986 period. Finally, scenarios are compared to the baseline over the simulation period: 1987-1992; this horizon is chosen to include a full production cycle. [11]

The introduction of expected risk and Canadian stabilization payments and the refinement of Canadian data are the main modifications used on the original data to improve the performance of the model for Canada. A detailed description of data and procedures is available in Spinelli (1991). [12]

Data Values and Sources

Expected Risk and Stabilization Payments

The pricing rule, based on perfect foresight, has been replaced by an adaptive expectations framework and allows the incorporation of a proxy for risk. The proxy for the risk

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[11] The hog production cycle describes the regular fluctuation in hog numbers due to changes in hog prices. A period of declining market price is generally followed by a reduction in herds and breeding capacity. Reduced numbers result in price increases a year to eighteen months later encouraging farmers to increase herds following this price strengthening. These fluctuations create a regular cycle of three to four years (Churches, 1988).

[12] Data can be obtained from the author.

associated with price variability of hogs is the standard deviation of the endogenous market prices for the 1981-1986 period. This variable does not cause much variation across regions (Table 5). Prices in Quebec, Ontario and Western Canada vary slightly less than prices in the Midwest but the difference is less than or equal to 2%.

To find the risk aversion coefficient, the model is run with different coefficients. The risk aversion coefficient, 0.3, is the parameter creating the best fit between simulated and actual data. The range of estimates used in other studies varies widely from 0.08 to 7 depending on methodology and sample (Bouzaher *et al.*, 1995).

Table 5 Standard Deviations 1981-1986 used in the Simulation Period as a Proxy for Risk

Region	Simulation period 1987-1992
Southeast	12.67
Midwest	12.73
Atlantic Canada	12.77
Quebec	12.64
Ontario	12.56
Western Canada	12.47

Income stabilization schemes, implemented to attenuate the impact of price variations, have been added to Spinelli's model. Quarterly data for federal stabilization payments are available from Agriculture Canada, but quarterly data for the Quebec Farm Income Stabilization Insurance Program (QFISIP) are not available since it is an annual program. It is assumed here that cash advances, which were provided three to eight times annually from 1987 to 1992, play a role in producers' expectations. Therefore, cash advances made when producers make decisions, i.e. three quarters before marketings, are used as proxies for expected subsidies. Like the risk aversion coefficient, the response coefficient to payments (0.12), is the parameter which provides the best fit between simulated and actual data and though low, is consistent with estimates found in the literature. Most econometric estimates suggest that Canadian hog production subsidies did not trigger an increase in Canadian hog production and exports, or if they did, the impact was small (Savard and Romain, unpublished manuscript).

Refinement of Canadian and US Trade Data

In Spinelli's 1991 thesis, all trade with the US is assumed to be with Eastern Canada and trade with Western Canada is ignored. In this thesis, Eastern Canada is disaggregated into Ontario, Quebec and the Atlantic provinces. Furthermore, data have been refined to record imports and exports into and out of the four Canadian demand regions, including Western Canada. Trade data from individual Canadian regions into or out of US regions are not currently available because trade with the US is reported by port not region of origin, or destination. It is not possible, for example, to distinguish between Canadian exports to the Southeast or the East if they cross at the same port. Trade is thus reported from each of the Canadian regions into and out of the US as a whole.

Refinement of Canadian and US Cost Data

Capital costs are not assumed to be identical across regions as they are in Spinelli (1991). Fortin and Salaun (1995) have calculated amortizement and interest costs in Quebec, Ontario, Alberta and Iowa. Costs in Quebec, Ontario and Alberta are 1.33, 1.5 and 1.54 times higher than in Iowa. The conservative value of 1.3 is chosen and multiplied by US$737, the capital cost per pig (for a production of 780 pigs per quarter) to obtain one-time, per pig capital costs of US$960 in all regions except Iowa.

Costs are incurred to market hogs and pork. Canadian hog marketing costs are obtained from provincial Marketing Boards. Spinelli's (1991) estimated pork wholesale-retail marketing margins are replaced by actual data from the USDA and all regions are assumed to have the same margins.

The same assumption is made for slaughtering and processing costs. Considering the lack of information for individual plants, standardization across regions is chosen. Klein *et al.* (1995) provide slaughtering capacities at the provincial level, which is insufficently disaggregated. Information on plant capacity, on the age of the equipment, labor contracts in force, and the potential number of labor shifts are necessary to assess cost differences (Bressler and King, 1970).

Spinelli's slaughtering and processing costs of US$22.88 per head for all regions are kept since this value is reasonable based on Ward and Faminow's (1992) estimates. Those authors surveyed US meat packers and asked executives about the per head cost of slaughtering-processing for three sizes of plants. Respondents estimated average costs of US$18.67, US$21.42 and US$23.5 per head for plants with annual volumes of 3.8, 2.7 and 1.6 million head, respectively. According to the authors, these costs are "informed estimates" since the sample is not statistically representative.

Refinement of Canadian and US Coefficients

The percentage of piglets lost during the weaning period is found in Table 6. Data for Canada are taken from Fortin and Salaun (1995) while data for the Midwest and the Southeast are kept identical as in Spinelli (1991).

Table 6 Quarterly Death Rates of Piglets by Region

Region	Death Rate (%)
Southeast	0.2
Midwest	0.2
Atlantic Canada	0.15
Quebec	0.135
Ontario	0.138
Western Canada	0.131

Dressing percentage from liveweight to carcass weight is set at 71% in the US and at 68% in Canada, Canadian pork being leaner. This information is based on electronic data from the USDA (1976-1995) and various issues of Livestock and Animal Products from Statistics Canada as shown in Table 7, which identifies all sources of data.

Table 7 Sources of Data for the Economic Model

Data	Source
Initial Herd Population	
US	USDA, NASS, Hogs and Pigs, various issues
Canada	CANSIM database, Matrix 9500-9510
Feed Prices	
US corn	USDA, NASS, Annual Price Summary, prices received
US Soy Bean Meal(44% protein)	USDA, NASS, Annual Price Summary, prices paid
Canada Wheat, Corn and Barley	Agriculture and Agri-food Canada, Policy Branch, Economic and Policy Analysis Directorate
Supplements	Feedstuffs, May 22, 1989
Non-feed Variable Costs	
US and Canada	USDA, ERS, Economic Indicators of the Farm Sector, various issues
Marketing Costs	
US	USDA, ERS, Economic Indicators of the Farm Sector, various issues
Canada	Various Provincial Hog Marketing Boards
Consumer Price Indices, Exchange Rates	
US and Canada	Agriculture and Agri-food Canada, Policy Branch, Economic and Policy Analysis Directorate
Regional Nominal Income	
US	US Department of Commerce, Bureau of Economic Analysis, Local Area Personal Income, Microfiche 2708-49, various issues
Canada	Agriculture and Agri-food Canada
Pork Trade, Military Shipments and Shipments to Territories	
US	USDA, ERS, Livestock and Meat Statistics

Table 7, continued.

Data	Source
Canadian pork imports and exports	Agriculture and Agri-food Canada
Regional Human Population	
US	US Department of Commerce, Census Bureau, Current Population Report, Publication 2542-1, various issues
Canada	Agriculture and Agri-food Canada
Retail Chicken and Beef Prices	
US	Agriculture and Agri-food Canada
Countervailing Duties	
US countervail	Canadian Pork Council
Stabilization Payments	
Canadian (federal)	Agriculture and Agri-food Canada
Quebec	Régie des Assurances Agricoles du Québec
Frozen Storage Quantities	
US	USDA, ERS, Livestock and Meat Statistics
Canada	Statistics Canada, Livestock and Animal Products, Catalogue 23-203
Distances between Production, SPS and Demand Centers	
US and Canada	Rand McNally, US/Canada Atlas
Area Owned or Rented by Hog Producers	
US	Unpublished Farm Costs and Returns Survey data, 1994
Canada	Statistics Canada, Agricultural Census, Agricultural Division, Agricultural Profile of Canada, Table 25

Table 7, continued

Data	Source
Validation Data	
Herd Inventory	
US	USDA, NASS, Hogs and Pigs, various issues
Canada	Statistics Canada, Livestock and Animal Products, Catalogue 23-203
Slaughter	
US	USDA, NASS, Livestock Slaughter, Electronic data 1976-1995
Canada	Statistics Canada, Livestock and Animal Products, Catalogue 23-203
Prices	
US	USDA, NASS, Agricultural Prices
Canada	Agriculture and Agri-food Canada

Farm Level Technical Coefficients, Initial and recurring fixed costs at the production and SPS levels, transformation and transportation costs and slaughter house costs are given in Spinelli (1991)

Validation Tools and Results

The next section outlines the empirical tools used to validate the economic model and presents the results in Tables 8 and 9.

Empirical Tools Used for Evaluation

Comparisons between simulated results and actual data are made using root mean square error (RMSE), percentage RMSE (%RMSE) and Theil's inequality coefficients (U_1 and U_2). The sensitivity to discount rates and the dynamic response of the model are additionnal criteria chosen to evaluate the performance of the model.

The RMSE becomes the basis for many "goodness of fit" measurements since it measures the deviation of the simulated variable from the actual time path. Because the magnitude of error can be best evaluated by comparing it with the average size of the variable, the percentage RMSE is also presented (Pindyck and Rubinfeld, 1991).

Formula 1. RMSE

$$\sqrt{\frac{1}{n}\sum_{t=1}^{T}\left(Y_t^s - Y_t^a\right)^2}$$

Formula 2. Percentage RMSE

$$\sqrt{\frac{1}{n}\sum_{t=1}^{T}\left(\frac{Y_t^s - Y_t^a}{Y_t^a}\right)^2}$$

where Y^s_t and Y^a_t are the simulated and actual values for the variables in period t and n is the number of periods.

The two Theil's inequality coefficients, commonly called U_1 and U_2 statistics contain the RMSE in their numerators. The U_1 statistic is misleading, however, since its denominator depends on the absolute values of past predictions. The levels of U_1 were shown to be lowered by additive transformations of predicted and actual values of variables being tested (Leuthold, 1975). Nevertheless, the widespread acceptance of these statistics might be explained by their ease of interpretation as they are bounded by 0 and 1. When U_1=0, the statistics used in the model predicts values which accurately fit the data. If U_1=1, however, the predictive performance of the model is less than adequate. When U_1=1, simulated values are always 0, though actual values are non-zero, and non-zero predictions have been made when actual values are zero. Furthermore, simulated values may be positive (or negative) when actual values are negative (or positive) (Pindyck and Rubinfeld, 1991). The best use of the U_1 statistic is to compare alternative variables and regions.

Formula 3. Theil's U_1 Statistic

$$U_1 = \frac{\sqrt{\frac{1}{n}\sum_t \left(Y_t^s - Y_t^a\right)^2}}{\sqrt{\frac{1}{n}\sum_t \left(Y_t^s\right)^2} + \sqrt{\frac{1}{n}\sum_t \left(Y_t^a\right)^2}}$$

where Y^s_t and Y^a_t are the simulated and actual values for the variables in period t and n is the number of periods.

The U_2 statistic has the same numerator as the U_1 but a different denominator. The value of the U_2 statistic is still zero when simulations equal the actual data, but this statistic has no upper boundary. It's value is 1 when the simulation equals the naive prediction and has values greater than 1, when predictions are less accurate.

Formula 4. Theil's U_2 Statistic

$$U_2 = \frac{\sqrt{\frac{1}{n}\sum_t \left(Y_t^s - Y_t^a\right)^2}}{\sqrt{\frac{1}{n}\sum_t \left(Y_t^a - Y_{t-1}^a\right)^2}}$$

where Y^s_t and Y^a_t are the simulated and actual values for the variables in period t and n is the number of periods.

Even if a model has a small RMSE, U_1 and U_2, it must respond to stimuli in ways which are consistent with economic theory and empirical observation. The dynamic response of the model is thus an important evaluation criterion.

In addition, an important criterion of model performance is its sensitivity to the starting date of the simulation period, or minor changes in model parameters. This is especially true for large mathematical programming models where obtaining accurate estimates is more difficult. The sensitivity to discount rates is analyzed after comparing actual and simulated data.

Comparison of Simulated and Actual Data

Simulated and actual data are compared over the 1981-1986, and 1987-1992 periods (Tables 8 and 9 respectively). Since parameters of the original model were estimated using econometric regressions with data from 1976-1983, the first period includes three years of out-of-sample data: 1984, 1985 and 1986. The second period includes six years of out-of-sample data: 1987-1992. Since the 1987-1992 period is more recent, it was used for simulations.

Inventory, slaughter and live hog prices are variables chosen to validate the model. Inventory is the most important output of the economic model since it is the variable measuring the impact of changes in the hog industry on water quality. Slaughter is validated to assess linkages between the primary and SPS sectors. Finally, prices are validated since prices and quantities are the main components of welfare.

Table 8 Hog Inventory and Slaughter Validation Statistics for the 1981-1986 Period

	Root Mean Square Errors		Theil's U-Statistic		Mean Values		
Predicted Variable	RMSE	% RMSE	U_1	U_2	Simu-lated Value	Actual Value	Dif-feren-ce [1]
Hog Inventory					Million Head		%
North America	10.73	0.17	0.08	0.77	71.55	63.21	11
United States	10.44	0.2	0.09	0.87	62.06	53.14	14.8
Southeast	2.2	0.28	0.13	1.15	7.62	8.36	-10.2
Midwest	10.28	0.23	0.1	1.01	54.45	44.79	19.4
Canada	1.98	0.2	0.1	0.97	9.09	10.06	-9.5
Atlantic	0.11	0.29	0.16	1.52	0.3	0.39	-23
Quebec	0.77	0.25	0.12	1.09	2.8	3.13	-12
Ontario	0.69	0.21	0.11	1.05	2.75	3.28	-16.2
Western Canada	0.77	0.24	0.12	1.27	3.25	3.26	1.3
Hog Prices					Real US$/Cwt		%
Midwest	38.99	0.49	0.3	2.25	48.37	76.91	-37.1
Atlantic	24.99	0.39	0.22	1.66	48.95	58.1	-15.74
Quebec	24.62	0.4	0.21	1.68	49.63	58.61	-15.32
Ontario	26.07	0.42	0.23	1.83	49.44	58.18	-15.02
Western Canada	24.42	0.41	0.22	1.8	48.75	55.95	-12.86

Table 8, continued

Predicted Variable	RMSE	% RMSE	U_1	U_2	Simu-lated Value	Actual Value	Diffe-rence
Slaughter					Million Cwt		%
North America	13.1	0.38	0.16	1.2	47.43	41.76	12.79
United States	7.24	0.2	0.09	0.81	41.67	36.26	13.9
Northeast	0.8	0.27	0.14	1.02	2.94	2.82	2.87
South	0.68	0.1	0.05	0.42	6.2	6.19	-2.4
Midwest	6.77	0.27	0.12	1.07	31.64	26.16	19.62
West	0.28	0.24	0.14	0.98	0.88	1.09	-21.21
Canada	2.01	0.35	0.17	1.73	5.77	5.49	4.26
Atlantic	0.05	0.21	0.12	1.15	0.19	.24	-17.8
Quebec	0.48	0.25	0.14	1.15	1.55	1.91	-18.95
Ontario	0.71	0.42	0.24	1.93	1.16	1.73	-32.49
Western Canada	1.9	1.07	0.39	5.47	2.86	1.67	73.59

[1] Percentage differences between average simulated and actual values; Cwt: 100 pounds.

Table 9 Hog Inventory and Slaughter Validation Statistics for the 1987-1992 Period

	Root Mean Square Errors		Theil's U-Statistic Measures		Mean Values		
Predicted Variable	RMSE	% RMSE	U_1	U_2	Simu-lated Value	Actual Value	Diffe-rence
Hog Inventory					Million Head		%
North America	12.41	0.15	0.07	0.8	73.89	66.11	11.77
United States	10.87	0.2	0.09	1.06	64.77	55.47	16.78
Southeast	0.98	0.11	0.06	0.6	8.05	8.6	-6.5
Midwest	11.21	0.24	0.11	1.3	56.72	46.87	21
Canada	1.85	0.17	0.09	0.9	9.12	10.64	-14.2
Atlantic	0.15	0.24	0.2	1.23	0.33	0.41	-20
Quebec	0.62	0.2	0.11	1.05	2.51	3	-16.1
Ontario	0.52	0.16	0.09	0.78	2.83	3.12	-9.3
Western Canada	0.75	0.18	0.1	1.02	3.45	4.11	-16.06
Hog Prices					Real US$/Cwt		%
Midwest	38.67	0.65	0.42	2.45	25.03	59.42	-57.87
Atlantic	26.12	0.58	0.34	2.3	26.03	44.86	-41.97
Quebec	24.28	0.55	0.32	1.68	26.22	43.21	-39.32
Ontario	25.92	0.58	0.36	2.31	25.85	44.18	-41.5
Western Canada	23.94	1.05	0.33	2.2	25.16	41.46	-39.32

Table 9, continued

Predicted Variable	RMSE	% RMSE	U_1	U_2	Simu-lated Value	Actual Value	Diffe-rence
Slaughter					Million Cwt		%
North America	10.47	0.28	0.12	1.07	46.44	45.39	2.95
United States	6.69	0.17	0.08	0.87	40.54	39.27	4.08
Northeast	1.25	0.43	0.18	1.96	3.92	3.04	29.15
South	4.77	0.9	0.3	3.59	9.93	5.84	70.16
Midwest	4.39	0.15	0.08	0.74	25.69	27.9	-7.94
West	3.31	0.37	0.64	1.82	1.01		-59.58
Canada	1.16	0.19	0.1	0.91	5.9	6.12	-3.37
Atlantic	0.03	0.12	0.06	0.56	0.22	0.24	-5.05
Quebec	0.57	0.29	0.16	1.37	1.68	1.95	-13.84
Ontario	0.6	0.32	0.17	1.52	1.68	1.78	-5.69
Western Canada	0.27	0.13	0.06	0.63	2.32	2.15	7.65

Validation results (Table 8) for the 1981-1986 period are consistent across the hog production and slaughtering sector, overestimating Midwest hog and pork production by 19% which, in turn, overestimates US and North American production. According to U_1 statistics, all hog and pork production results are comparable except for pork slaughtering in Ontario and Western Canada. Price predictions are least accurate in the Midwest and all price underestimates are related to production overestimates in the Midwest, the largest production region where prices are determined. Predictions of some variables for certain regions are equivalent to predictions of a naive, no-change extrapolation model, based on the U_2 statistics in Table 9. Regardless, the results for Canada are better than those obtained by Spinelli (1991). Canadian and US results are adequate since the model does not forecast, but compares scenarios. As long as the model is stable, it can estimate the effects of policies by comparing across scenarios. In North America, overestimations of inventories (11.77%) and slaughter (2.97%), occur during the 1987-1992 period (Table 9). This overestimation is not equally distributed across regions: the overestimation of 21% in the Midwest is balanced by an underestimation in other regions.

Discrepancies between simulated and actual data on inventories and hence production and price are inevitable since certain costs are difficult to estimate and others are confidential. Further evidence that better cost data could improve the supply function is that North American and Midwest overestimates are reduced to 1.4% and 5.4%, respectively, when all regional costs are increased by 20%; Canadian inventories remain underestimated.[13]

The use of American data for certain Canadian variables (non-feed costs, wholesale-retail pork margins, chicken and beef retail prices, and transportation costs) may be responsible for differences between simulated and actual data for Canada.

[13]Detailed results are not reported.

Aggregate results at the North American level are better, over and underestimates tending to cancel each other.

Model predictions for the sum of live hog exports from Canada to the US, over the whole period, are good. The model simulates exports of 4.01 million head while the actual value is 3.92 million head. Quarterly exports, however, are not as accurate. In 1991, most hogs are exported in the second quarter, when there is no countervailing duty.

Predictions of quarterly pork exports, mainly from Western Canada to Western US, are better. Pork is exported even when a countervailing duty is applied and these conclusions do not change when the discount rate is lowered to test the model's sensitivity.

Sensitivity Analysis

The choice of the discount rate is somewhat arbitrary, and despite the fact that it is a subject of debate in the literature, often it is chosen to equal the interest rate. The sensitivity scenario consists of measuring the impact of discounting, but at a low rate. Lowering the discount rate increases the levels of inventory compared to the baseline, thus raising average inventory levels in most regions (Table 10). Lowering the latter rate from 8% to 1%, increases North American inventories by 4%, US inventories by 3% and Canadian inventories by 12%. North American slaughter levels are consistent with inventory levels varying by 5%. The percentage difference could be higher, following a decrease in the discount rate, if the base scenario did not contain a constraint imposing a fixed level of inventory at the North American level in the last quarter. The fixed level is set to prevent early liquidation of the herd that could be triggered by a high discount rate.

The model is not sensitive to the starting date of the simulation period. Starting the simulation in 1988 instead of 1987, does not significantly change the results and hence these results are not presented.

Table 10 Sensitivity Analysis for the 1987-92 Period

Regions	Baseline	Discount rate: 1%	Percentage Change from Base
	Average Hog Inventories in Million Head		
North America	73.89	76.93	4.11
US	64.77	66.73	3.03
Southeast	8.05	8.08	0.37
Midwest	56.72	58.65	3.4
Canada	9.12	10.2	11.84
Atlantic	0.33	0.33	0
Quebec	2.51	2.51	0
Ontario	2.83	3.88	37.1
Western Canada	3.45	3.49	1.16
	Average Slaughter Levels in Million Cwt		
North America	46.44	48.6	4.65
United States	40.54	42.46	4.74
Northeast	3.92	3.95	0.77
South	9.93	10.32	3.93
Midwest	25.69	27.09	5.45
West	1.01	1.11	9.9
Canada	5.9	6.14	4.07
Atlantic	0.22	0.23	4.55
Quebec	1.68	1.69	0.6
Ontario	1.68	1.82	8.33
Western Canada	2.32	2.4	3.45

Table 10, continued

Region	Baseline	Discount rate: 1%	Percentage Change from Base
	Sum of Live Hog Exports 1987-1992 in Million Head		
Canada to US	4.01	4.65	15.96
US to Canada	0	0	
	Sum of Pork Exports from SPS to Demand Sector 1987-1992 in Million Cwt		
Canada to US	4.75	6.33	33.26
US to Canada	30.6	29.12	-4.84

Dynamic Response of the Model

Results from the economic model presented in chapter VI, are consistent with theory and an increase in trade and decrease in prices in the importing country after removal of a countervailing duty is one example of agreement with theoretical predictions. A second example is the consistency of the short-run supply elasticity with data found in the literature. Short-run supply elasticity is not an input in the model, but can be calculated by measuring percentage changes of hog marketings over percentage farm price changes three quarters earlier. The quantity changes include both shifts in, and movements along the supply curve. The choice of using four quarters for the shortterm eliminates seasonal effects on supply. The supply elasticity over four quarters is 0.19 for the two US regions, 0.06 for Quebec, 0.09 for Ontario, 0.08 for Western Canada and 0.11 for the Atlantic provinces while Moschini and Meilke (1993) report a short-run hog supply elasticity of 0.042.

Possible Modifications

The impact of grain programs which can influence hog production could be incorporated. For example, Canadian grain transport policies[14] have caused pork production to shift from Western Canada where there was a grain surplus to Eastern Canada, traditionally facing a grain deficit, by subsidizing the movement of feed grains to deficit regions.

Adding Mexico as a trading partner would allow the simulation of environmental and economic impacts of the North American Free Trade Agreement.

Finally, incorporating economies of size in productivity-enhancing technologies would improve the cost structure of the model.[15] To take advantage of economies of size, the farm structure is evolving into fewer, larger firms clustering near

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[14]Transport subsidization ended in 1996, but had an impact during the simulation period.

[15]The manure-related capital requirements per sow unit in British Columbia decreased from CND$1,088 for a 100-sow unit to CND$616 for a 400-sow unit (Fullerton, 1990). Furthermore, in 1990, production costs were US$60 per hundredweight on a 140-head farm compared with less than US$45 per hundredweight on a 10,000 head farm (Pagano and Abdalla, 1994).

processing facilities with specialized infrastructures (Pagano and Abdalla, 1994).

> Arkansas' Tyson Foods Inc., one of the companies that earlier transformed poultry into an automated conception-to-consumption business, is turning to pork... Pork is where poultry was in the 1970s, says John Tyson. Now the train is leaving the station. (Globe and Mail, April 1, 1994).

Large-scale operations, characterised by lower costs, increased coordination, and improved quality, could be responsible for a 15% net growth of the industry over the next decade (Hurt, 1994). Indeed, North Carolina and Quebec have experienced major increases in hog production and concentrations of farms. In North Carolina, pork production increased from 839 million pounds to 1,473 million pounds per year from 1984 to 1991, an increase of over 75% (Roka, 1993). Farms of 1,000 head or more, whose numbers increased by 47% between 1987 and 1992, made a major contribution to the development of the industry (Smith and Kuch, 1995). In Quebec, the largest growth of the hog industry occurred between 1976 and 1980 with an increase in hog inventories from 1.5 million in 1975 to 3.5 million in 1980. Production has since levelled off, but the number of farms fell from 8,000 in 1981 to 3,614 in 1991 through the consolidation of farms (Karantininis *et al.,* 1995). This concentration increases the burden on local environments even if large-scale swine production units spend less on fertilizer, and utilize more manure nutrient value than smaller firms (Van Arsdall and Nelson in Purvis and Outlaw, 1995).

CHAPTER V - THE ENVIRONMENTAL MODEL

The Erosion Productivity Impact Calculator (EPIC) is the environmental model which is linked to the economic model. Different quantities of manure, corresponding to live hog inventories under different policies are inputs into EPIC and measure the impact of alternative scenarios on water quality (Figure 1).

EPIC was developed by the US Department of Agriculture Agricultural Research Station (USDA-ARS) to assess the productivity and erosion problems related to cultivation practices (Williams *et al.*, 1984 cited in Lakshminarayan *et al.*, 1996), but often is used to address water quality issues. This chapter places EPIC within the large ensemble of models. Later, EPIC is described and the rationale behind the choice of environmental indicators, nitrates, and phosphates, is given.

EPIC inputs and outputs are identified followed by validation results and proposed modifications to the present methodology.

Description of Chemical Transport Models

Most chemical transport models addressing water quality contain standard components such as: surface-runoff, groundwater, and erosion components (Antle and Capalbo, 1993).

In the surface-runoff generation component, which describes the transformation of precipitation into runoff, the soil surface and soil profile are major controls for the response of the surface water system. Land use practices such as tillage, affect the infiltration, runoff, and erosion processes. The US Department of Agriculture Soil Conservation Service Curve Number model is commonly used to estimate runoff. This method relates direct runoff to daily rainfall as a function of a curve number representing soil type, soil drainage properties, crop type, and management practice.

A second component of the transport models is the groundwater component which describes chemical movement through the unsaturated soil zone and sometimes into the saturated zone. These models estimate the partitioning of a chemical between adsorbed particles and dissolved chemicals and determine the portion of chemical transported by soil sediment or soil water. Volatilization and decay of chemicals may also be modelled.

A third component of many transport models is the erosion component, which estimates soil loss. This is important since a nutrient that is transported off the field via eroded soil is not available for leaching to groundwater. The Universal Soil Loss Equation, which accounts for rainfall, crop management, slope conditions, and erosion control practices, is a model that has been used in the past to calculate soil loss per acre.

Chemical transport models containing the three components can be divided into three broad categories: research, management, or screening models. Research models provide quantitative estimates of water and solute movement, but usually have extensive data demands on the system to be simulated (e.g. daily or hourly climate data). Management models are less data-intensive, less quantitative in design, and less robust at predicting water and solute movement under various environmental conditions. The screening models have relatively low data demands, can evaluate and compare nutrient transport and fate under alternative environmental conditions, and are relatively inexpensive to use. One output of these models is the categorization of chemicals into broad behavioral classes.

The performance and characteristics of twelve models described in the literature and belonging to the three different categories are reviewed.[16] Bingner *et al.* (1987) compared the performance of CREAMS, SWRRB, EPIC, ANSWERS AND AGNPS in estimating runoff and sediment yield. No significant difference

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[16]Acronyms used in this chapter are defined as follows:
AGNPS, Agricultural Nonpoint Surface Pollution model
CREAMS, A field scale model for Chemical, Runoff, and Erosion for Agricultural Management Systems
SWRRB, Simulator for Water Resources in Rural Basins
EPIC, Erosion Productivity Impact Calculator
ANIMO, Agricultural Nitrogen Model
DAISY, Danish Simulation model for transformation and transport of matter and energy in the soil plant atmosphere system
RENLEM, Regional Nitrogen Leaching Model
SWATNIT, Soil Water Actual Transpiration and Nitrogen model
ANIMO, Agricultural Nitrogen Model
LONFAS, Leaching of Nitrate from Agricultural Soils
NMIN, Mineral Nitrogen
NTRM, Nitrogen Tillage Residue Management
SWATRE, Soil Water Actual Transpiration Rate Extended

was observed between the yearly, measured and predicted values of runoff at the 95% confidence level among the five models for the Flannigan watershed. Vereecken *et al.* (1991) compared nitrogen leaching and crop uptake by EPIC, RENLEM, ANIMO, DAISY and SWATNIT and the main features of their results are reported below. For all sites, DAISY explains about 90% of the measured variability with a root mean square error (RMSE) of 27.2%. ANIMO and EPIC have about the same performance explaining 78% and 77%, respectively, of the variability with RMSE values of 36.2% and 37.1%, respectively. The lowest performance is obtained by RENLEM and SWATNIT, explaining only 52% of the variability with a RMSE of 53%. Before discussing the performance of the models in predicting the plant uptake of nitrogen, only EPIC and DAISY simulate crop production and the corresponding demand for nitrogen. SWATNIT and ANIMO use a potential nitrogen uptake function which varies according to the availability of nitrogen in the soil profile. In RENLEM, the plant nitrogen uptake is an input, and for all sites, RMSE values vary between 15.2% and 22.9%. Results are overestimated with DAISY and SWATNIT and underestimated with ANIMO. EPIC overestimated uptake on one site and underestimated it on two other sites.

Since the relative performances of different models varies according to site specificities, the choice of model is based on the model characteristics. Vereecken *et al.* (1991) include several tables describing nine models: NTRM, EPIC, CREAMS, RENLEM, ANIMO, LONFAS, NMIN, DAISY and SWATNIT. Only five of the models include animal manure as a source of nitrogen: NTRM, EPIC, RENLEM, ANIMO AND DAISY, and from these, EPIC, NTRM and DAISY are research models as opposed to management models for decision analysis. Finally, according to Leavesley *et al.* (1990), EPIC provides the most detailed and complete simulations of nitrogen and phosphorus fractions and transformations. Hence, EPIC was selected as the most suitable model for this study. The model has been calibrated for North America, is well documented, and includes the desired indicators.

The Erosion Productivity Impact Calculator (EPIC)

EPIC is a comprehensive research model, developed specifically for analyzing the erosion/productivity problem. The drainage area is generally small (i.e. around one hectare), because model parameters are assumed to be spatially homogeneous; hence it is a field-scale physical process model (Lakshminarayan *et al.*, 1996). In vertical directions, the model can work with any variation in soil properties (Sharpley and Williams, 1990). It has ten components: weather, hydrology, erosion, nutrients, soil temperature, crop growth, tillage, plant environmental control, pesticide fate, and economics (Table 11).

Table 11 Components of the EPIC Model

Component	
Weather	Daily inputs of precipitation, maximum and minimum temperature, solar radiation, wind, and relative humidity; collected and/or generated inputs can be used
Hydrology	Processes of surface runoff, percolation, lateral subsurface flow, evapotranspiration, and snow melt
Erosion	Wind and water erosion are simulated; three options are available to simulate water erosion
Nutrients	Processes of nitrogen and phosphorus transformations, crop uptake, leaching, and runoff (both solution and eroded phases)
Soil temperature	Calculated as a function of air temperature and ground cover
Crop growth	A generic crop growth model is used that permits the simulation of complex rotations
Tillage	Different levels of tillage can be simulated; specific implements are accounted for
Plant environment control	Different levels of irrigation, fertilizer, and lime; drainage and furrow diking can be simulated
Pesticide fate	Pesticide routines from the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model have been incorporated; processes of pesticide degradation, leaching, and runoff (both solution and eroded phases)
Economics	Crop budgets and accounting subsystem keeping track of the costs of producing and marketing the crops and incomes generated from the activity

Source: adapted from Bouzaher *et al.* (1993a)

An important feature for this study is the nutrient component which comprises both the nitrogen and phosphorus cycles, environmental indicators chosen for reasons explained in the following.

Environmental Indicators

Water quality is a multidimensional concept including physical, chemical and biological indicators. Bouzaher *et al.* (1993b) summarize ground and surface water indicators of nonpoint source pollution from animal waste runoff. They use nitrite plus nitrate nitrogen, ammonium nitrogen, Kjeldahl nitrogen, phosphate, chloride and sodium for groundwater, total suspended solids and variably suspended solids, total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, soluble phosphorus, chloride, pH, Biological Oxygen Demand, and coliform bacterial count for surface water.

This study, in contrast to an Environmental Impact Assessment which considers a broad set of indicators, and in line with the tradition of cost-benefit analysis which uses one indicator, uses two environmental indicators; nitrates and phosphates. They are the most commonly regulated nutrients in legislation which protects water quality. They are also widespread, detectible, and associated with specific problems. Pollution from copper, for example, is specific to farms where it is included in feed. Nitrate and phosphate losses are widespread and detectible before they reach a specified threshold. Even at low concentrations, nitrates and phosphates are responsible for environmental and health hazards identified in the introduction. Phosphates being less soluble than nitrates, are lost mainly in runoff and erosion, and hence affect surface water, while nitrates are lost in runoff and leachate contaminating surface and groundwaters.

The levels of the two indicators are assessed under specific management practices described in the next section after the outline of selected inputs and outputs.

Data Inputs

The impact of different scenarios on water quality is simulated with EPIC at two sites; Raleigh, North Carolina and Pont-Rouge, Quebec. Since the objective of this study is to compare scenarios rather than to assess cumulative regional environmental impacts, simulations with EPIC are done on small areas within each region.

Important parameters used to reach the objectives of this thesis are presented in Table 12. Input files, which can be obtained from the author, include the following monthly data on the weather: average monthly maximum and minimum air temperatures, monthly standard deviation of the maximum and minimum daily air temperatures, average monthly precipitation, monthly standard deviation of the daily precipitation, monthly skew coefficient for daily precipitation, monthly probability of a wet day occurring after a dry day, monthly probability of a wet day occurring after a wet day, average number of days of rain in a month, and average monthly solar radiation. Daily precipitation, air temperature, and solar radiation are generated stochastically using the EPIC weather generator and information provided above.

The input files also include the following data for each soil layer: depth of the soil layer, bulk density of the soil layer, wilting point, field capacity, sand content, silt content, organic nitrogen concentration, soil pH, organic carbon content, coarse fragment content, nitrate concentration, labile phosphorus concentration, and crop residue concentration.

Table 12 Selected EPIC Inputs Specified by the User

Input Variable	Units	Quebec	North Carolina
General Data			
Watershed drainage area	hectare	15[17]	1
Runoff curve number		65	69
Average channel slope	m/m	1	0
Channel roughness factor		0.1	0
Surface roughness factor		0.1	0.41
Latitude	degrees	51	35.65
Average watershed elevation	m	100	100.6
Water content of snow on ground at start of simulation	mm	67	NA
Average concentration of nitrogen in rainfall	g/m^3	0.9	0.8
Concentration of carbon dioxide in atmosphere	PPM	330	350

[17]When the model is run with a drainage area of 1 ha, the level of nitrates in runoff and groundwater are the same, and the level of phosphates in runoff changes from 0.55 to 0.51 kg/ha with an input of 60 kg of N per ha.

Table 12, continued

Input Variable	Units	Quebec	North Carolina
Water Erosion Data			
Slope length	m	140	10
Number before decimal specifies water erosion equation (0=MUSLE 1=AOF 2=USLE). Number after decimal is slope steepness		0.01	0.05
Erosion control practice factor		1	1
Wind Erosion Data			
Field length	km	1	2
Field width	km	0.3	2
Clockwise angle of field length from North	degrees	0	90
Standing dead crop residue	t/ha	1	0
Soil Data			
Soil albedo		0.1	0.18
Maximum number of soil layers		5	10
Minimum thickness of maximum soil layer	m	0	0
Initial soil water content-fraction of field capacity		0.8	0
Minimum depth to water table	m	0.5	[1]
Maximum depth to water table	m	8	[1]

Table 12, continued

Input Variable	Units	Quebec	North Carolina
Initial depth to water table	m	2	[1]
Soil weathering code		2	[1]

[1] not needed since leaching is not simulated; NA: not applicable

Management practices differ between the two regions since they follow the guidelines for experiments used for validation. Rather than including management information data in table 12, it is described in separate sections for the two sites studied.

Management Information for North Carolina

In North Carolina, the experiment described by Burns *et al.* (1987) is reproduced with EPIC. Elevation, latitude, mean climate norms, and mean wind speed and direction are from the Raleigh, US Department of Agriculture Agricultural Research Station (USDA-ARS). The station is located approximately 8 km southeast of the experimental plots and is assumed to have mean climate norms representative of, if not identical to, those which prevail over the experimental plots. No special wind or water erosion control practices are installed.

The soil pedon description for the Cecil sandy clay loam (clayey, kaolinitic, thermic Typic Hapludults) is obtained from the EPIC soil database. Prior to the manure treatment, the simulation allows for six years of low fertility/low yield when the summer pasture is established. Summer and winter pastures, simulated by EPIC, are composed predominantly of tall fescue as were pastures from which the North Carolina experimental data were obtained. The plots are then irrigated with effluent during four years. The effluent irrigated is assumed to contain 0.1% solids and the frequency of applications for the study period is given in Table 13.

Table 13 Frequency of Effluent Irrigations on the Experimental Site

Month	First Year	Second Year	Third Year	Fourth Year
March			5	3
April			4	4
May	4	4	4	4
June	4	4	4	5
July	5	5	4	4
August	4	4	4	4
September	4	4	4	5
October	5	5	4	5
November	2	2	2	2

Source: personal communication with J.C. Burns, Professor, Department of Crop Science and Animal Science, North Carolina State University.

Periodic grazing is too difficult to control on individual plots, and is thus simulated by using periodic harvesting of plots with a mechanized harvester. Harvests on the experimental plot are hence more frequent than harvests to sell the crop. The dates on which 95% of the standing pasture biomass are harvested are given in Table 14.

Table 14 Harvest Dates for the Experimental Period

Month	First Year	Second Year	Third Year	Fourth Year
March		29	28	
April	7		18	20
May	5	3,19	11,31	12,31
June	5	8,30		22
July	24			24
August	13	11,28	30	16,21
September		13,22		8,21
October	8	7,22	4	5
November			14	
December	20			13

Source: personal communication with J.C. Burns, Professor, Department of Crop Science and Animal Science, North Carolina State University.

In the next section, management practices for Pont-Rouge, Quebec are identified. Less data, for management practices, are required in Quebec than in North Carolina: due to the shorter and cooler summer season, forage is harvested less frequently (in Quebec, forage is harvested three times a year compared to seven to eleven times in North Carolina) and manure is spread twice a year in Quebec while, in North Carolina, fields are irrigated with slurry once a week.

Management Information for Quebec

The database from the Soils Department at Laval University for Portneuf county is used to run EPIC in Quebec. The climate is based on that of Sainte-Catherine. Management practices reported in Gangbazo *et al.* (1995) are performed on the Pont-Rouge soil, a Morin soil with more than 10% gravel at depths below 60 cm. The sand content varies from 83% to 99.5%, depending on soil depth and plot analyzed. Clay and organic matter content decrease with depth. Wind speed and direction are not incorporated.

For five years before the experiment, the land is under summer pasture. After this period, two simulation series are run; one with silage corn and the other with forage. Crops are planted before any manure application, which averages 4.8% dry matter.

Forage is harvested on June 21st, July 10th and October 7th. Since harvest is not as frequent in Quebec as it is in North Carolina, nutrient absorption by forage is not as large in Quebec as in North Carolina.

Output Variables

As mentioned previously, nitrates and phosphates are the two environmental indicators. Hence, from the 158 EPIC output variables, variables of greatest interest are: 1) nitrate loss through runoff, 2) soluble phosphate loss through runoff and 3) crop yield.

The mineral nitrogen loss in percolate is an output variable for Quebec but not for North Carolina. The percolation of nitrates beyond the rooting zone is largely determined by the depth and movement of groundwater and by the rooting depth. Experimental data from the North Carolina study are expressed in terms of nitrate concentration as a function of soil depth, but gives no information on the depth of the groundwater table, or the rooting depth. Validation of the nutrient losses in groundwater in North Carolina is therefore impossible.

Furthermore, the experiment in Quebec included both corn and forage while the North Carolina study was performed on forage only. Simulated results with corn could not be validated for North Carolina.

Three options are available regarding the choice of variables for comparison: 1) report simulation results on corn, and the percolation of nitrates in groundwater in North Carolina, even though they are unvalidated, 2) focus upon variables that can be validated in both regions, or 3) report more results of simulations in Quebec than in Carolina which creates an unbalanced comparison design. The third option is chosen, since the objective is to assess the impact of various policies on water quality using two case studies, not to perform a systematic comparison between two regions.

Unfortunately, less data are available for the environmental model and validation of results is more difficult than for the economic model. Conducting field experiments to obtain data necessary to perform a statistical analysis was not feasible due to the resource demands needed to run the economic model.

Validation Results

Results from experiments performed in Raleigh, North Carolina and in Pont-Rouge, Quebec, described in the previous section, are compared to the simulated results to validate the model. Rather than annual data, averages are compared, which is preferable since the weather data are generated stochastically by EPIC. This procedure introduces additionnal discrepancy between annual simulated and actual data.

Two simulations, corresponding to two treatments, are used in each region for the validations. Results from North Carolina are followed by validation results from Quebec. Additionnal simulations are run to establish relationships between inputs of manure fertilizer and output variables (Figures 5 to 7 in chapter VI).

Validation Results for North Carolina

In the experiment performed in North Carolina (Westerman *et al.*, 1987), two effluent irrigation treatments were used for hog lagoon effluent: 200 mm per year (about 600 kg N/ha/year) and 400 mm per year (about 1200 kg N/ha/year). Yield and runoff levels of nitrogen and phosphorus following these treatments are compared to experimental data in Table 15.

Average simulated levels of nutrients in runoff over four years is compared to the experimental data collected on the final sampling date. The total nitrogen in runoff was recorded, while EPIC simulates the level of nitrates, the principal form of nitrogen in runoff.

Table 15 Comparison between Simulated and Experimental North Carolina Data [1]

		First Treatment		Second Treatment	
		Sim.	Exp.	Sim.	Exp.
Runoff-N	kg/ha	Nitrates 12.52 (-3.69)	Total N 13 [2]	Nitrates 27.55 (-55.56)	Total N 62 [2]
Runoff-P		2.35 (-2.08)	2.4 [2]	7.35 (-61.32)	19 [2]
Yield	t/ha	10.7 (-4.21)	11.17 [3]	10.7 (-14.4)	12.5 [3]

[1] Percentage differences between actual and simulated values are in parenthesis [2] Source: Table 4 (Westerman *et al.*,1987)
[3] Source: Table 4 (Burns *et al.*,1987)
Sim.:Simulated; Exp.:Experimental; kg/ha:kilogram per hectare; t/ha:tonne per hectare; Total N: total nitrogen consisting of ammonium nitrogen and nitrates.

Simulation of the first treatment is accurate while simulation of the second treatment is not. Hence, the model is not used in the higher spectrum, represented by the second treatment, to establish relationships between inputs and outputs in Chapter VI: the highest simulated application is 820 kg N/ha. An application of 684 kg of N/ha is used as the base scenario for comparisons (identified as common practice).[18] It is higher than the first treatment but considerably lower than the second treatment (1200 kg).

Two treatments are also used to validate the results in Quebec, both of which provide insight into the relationship between EPIC input and output variables as discussed next.

Validation Results for Quebec

Simulated results for Pont-Rouge, Portneuf, are compared with results from the experiment conducted in Lennoxville by Gangbazo *et al.* (1995) to determine if they are within a reasonable range. The first treatment consisted of an application, in the spring, of chemical fertilizer at the recommended rate, according to the nitrogen requirements: 180 kg

[18]Recommended nitrogen application rates range from 40 to 50 lbs of nitrogen per dry ton of bermudagrass hay (Zublena *et al.* cited in Cox, 1993). An average of 45 lbs is multiplied by the crop yield of 11.17 t/ha (Burns *et al.*, 1987) to give 228 kg/ha. Three times the recommended rate corresponds to 684 kg/ha.

of N/ha on corn and 55 kg on forage without hog manure (Association des fabricants d'engrais du Quebec cited in Ganbazo, 1995). With the second treatment, the recommended rate of fertilizer was applied with hog manure at twice this rate: 180 and 55 kg of nitrogen from manure were applied in the spring (May 21-25) and fall (October 1-30) on corn and forage, respectively. Averages over the experimental period are compared in Table 16.

Table 16 Comparison between Simulated and Experimental Quebec Data [1]

Crop	Variable		First Treatment [2]		Second Treatment [2]	
			Corn:180-0-0 Forage:55-0-0		Corn:180-180-180 Forage:55-55-55	
			Sim.	Exp.	Sim.	Exp.
Corn	Runoff-N	kg / ha	3.17 (-2.16)	3.24	6.43 (46.8)	4.38
	Runoff-P		0.51 (-19.05)	0.63	0.64 (30.61)	0.49
	Leaching -N		15.5 (-69.18)	50.29	62.48 (-48.8)	122.03
	Crop Uptake-N		145 (91.04)	75.9	150 (58.39)	94.7
	Crop Uptake-P		20.7 (9.52)	18.9	21.15 (-15.74)	25.1
	Yield	t/ ha	8.3 (45.61)	5.7	8.46 (19.15)	7.1
Forage	Runoff-N	kg / ha	1.35 (84.93)	0.73	1.67 (234)	0.5
	Runoff-P		0.20 (-65.52)	0.58	0.28 (-44)	0.5
	Leaching -N		2.02 (-81.21)	10.75	3.81 (-73.71)	14.49
	Crop Uptake-N		86 (-12.07)	97.8	102 (-5.99)	108.5
	Crop Uptake-P		12.24 (17.69)	10.4	14.42 (33.52)	10.8
	Yield	t/ ha	3.71 (-15.68)	4.4	4.37 (-5)	4.6

[1] Percentage differences between actual and simulated values are in parenthesis [2] Mineral fertilizer-Spring manure-Fall manure (kg/ha) Sim.:Simulated; Exp.:Experimental; kg/ha:kilogram per hectare; t/ha:tonne per hectare.

Results for levels of nutrients in runoff are reasonable, while simulated results for leaching are lower than the experimental data. The level of phosphates in runoff is also underestimated by the simulations. Underestimation of nitrate leaching and phosphorus runoff can be explained partly by the fact that during the second year of the experiment, winter precipitation was more than twice the 29 year average. Also, each of the three winter seasons had a large number of days with temperatures that were mild enough to initiate snowmelt runoff and subsurface drainage. Even if the total annual precipitation for each of the three years was comparable to the average, single events could significantly increase nutrient losses in the field. This is particularly true for phosphorus, which accumulates in the soil (being less soluble than nitrogen) and is, in part, washed away during storms. Unfortunately EPIC does not simulate losses due to unusual events such as major storms.

Furthermore, nitrate leaching might be underestimated because the simulation period is eight years while it can take up to forty years for nitrates to leach to groundwater (Hanley, 1990). Thus, for this reason environmental impacts are expected to be worse than what is shown by simulated results.

Simulated nitrogen crop uptakes by forage are 12% and 6% lower than the experimental results for the first and second treatments. These results are better than those obtained by Engelke and Fabrewitz (1991), who underestimated N-uptake by grass by 28% to 56%.

Sensitivity Analysis

Sensitivity to incremental changes in manure applications can vary with application levels. Applications of manure are increased to reach leaching levels similar to experimental results reported in Table 16. The base scenario consisting of applications of 540 and 165 kg of N is replaced by applications of 720 and 385 kg N on corn and forage respectively.

Scenario 2 simulating the removal of the pork and hog countervailing duties and stabilization payments does not induce any significant change in the levels of nitrates in drainage with either base scenario. Scenario 3, which adds the removal of the ban on US imports of live hog into Canada to scenario 2, triggers a decrease of 1.73% and 4.98% in the levels of nitrates in drainage under corn and forage cover respectively. These results are different from the ones reported in Table 21 where the nitrate level decreases by 2.58% and 1.3% on corn and forage respectively showing that relationships between nutrients inputs and outputs are not linear. However, these differences do not change the qualitative nature of the conclusions. Scenario 2 has no impact on water quality while scenario 3 improves groundwater quality.

Possible Modifications

An alternative approach would be to use a metamodel, a statistically based, spatial sampling design, to obtain results for the physical model at a larger scale i.e. for a watershed, a province, or nation (Lakshminarayan *et al.* 1996). Secondly, an extension to the present methodology would incorporate an aquifer model aggregating different pollution flows to estimate the stock of pollution. This would give the nitrate concentration in the aquifer which could be compared with the Canadian standard of 10 mg/L. This standard is not, however, set for flows of pollutant in runoff or leachate. Environmental indicators in this thesis estimate flows rather than stocks of pollutants.

The organic nitrogen and the phosphorus losses with sediment are simulated with EPIC and could be additionnal indicators since soil losses can be carried to surface waters.

Finally, EPIC could be modified to simulate the water contamination by ammonium nitrogen. In the EPIC nitrogen cycle, after ammonium nitrogen is applied as a component of manure, it is assumed to be immediately lost via volatilization, or transformed into nitrates by nitrification. This assumption is based on the fact that ammonium nitrogen is rapidly nitrified in well aerated soil at temperatures between 10 and 30 $^{\circ}C$. Ammonium nitrogen can cause three types of problems, however, even at very low concentrations. For example, concentrations of <0.02

mg/L may increase the risk of fish asphyxia (McNeely *et al.* cited in Ganbazo, 1995). During water treatment, ammonium nitrogen reacts with chlorine and produces chloramines which are less effective as disinfectants. Finally, ammonium nitrogen may cause problems with taste and smell, even at concentrations as low as 0.1 mg/L (Boucher cited in Ganbazo, 1995).

CHAPTER VI - ANALYSIS AND EMPIRICAL RESULTS

As stated in the introduction, the first objective of this study is to design a framework to measure the impact of trade, agricultural and environmental policies on water quality. The second objective is to assess the impacts of trade and market welfare under various combinations of agricultural, environmental, and trade policies.

To reach the first objective, the quantity of manure nitrogen to insert into EPIC must first be determined. The quantity of manure being a function of live hog inventories, the impact of trade scenarios on hog inventories is discussed in the next section. The quantity of manure nitrogen used in EPIC, under nutrient management plans, is the topic of the second section. Finally, the effect of regulations on hog management and water quality are discussed.

Manure Nitrogen Inserted into EPIC under Two Trade Policies

To measure the impact of trade and agricultural policies on water quality using EPIC, the percentage change in live hog inventories (and hence, in manure), obtained by running the economic model under two trade scenarios (2 and 3), must first be found, since the quantity of manure is an input in EPIC.[19] Scenario 2 involves the elimination of the hog countervailing duty and stabilization programs while scenario 3 simulates a free trade environment by adding to the measures in scenario 2, the elimination of the ban on live US hog imports in Canada (nontariff barrier). Percentage changes in the Southeast and in Quebec are reported in Table 17.

Table 17 Impact of Trade Scenarios on Hog Inventory Percentage Changes Compared to the Baseline

Regions	Scenario 2	Scenario 3
	% Inventory Change from Baseline	
Southeast	-0.13	-0.02
Quebec	-0.08	-2.96

Both inventories in Quebec and in the Southeast decrease, following the removal of countervailing duties (scenario 2). Removal of the nontariff barrier (scenario 3) induces a decrease of inventories in Quebec of 2.96% and in the Southeast of 0.02%.

As described in Chapter III, the kilograms of nutrients applied to fields under the common practice increase or decrease according to percentage changes in Table 17. For example, the

[19]Scenario 1 simulates the removal of the pork countervailing duty. Since it has already been removed, it is less relevant than scenarios 2 and 3. Furthermore, the percentage difference in hog inventories between scenario 1 and the baseline is only -0.06 in the Southeast and -0.001 in Quebec.

common practice in Quebec is to apply 165 kg N/ha (55 kg from fertilizer and 110 kg from manure) on forage and 540 kg on corn (180 kg from fertilizer and 360 kg from manure). Removal of the nontariff barrier triggers a decrease of inventories in Quebec by 2.96%, hence the kilograms of nitrogen are decreased by 2.96% from 165 to 160 kg on forage and from 540 to 524 kg on corn.

The number of kilograms of manure nitrogen used as an input in EPIC under the trade and environmental scenarios, is summarized in Table 18. The procedure to determine the number of kilograms of nutrient applied, to comply with nutrient management plans, is described in the next section.

Table 18 Impact of Trade and Environmental Scenarios on Kilograms of Nitrogen (N) and Phosphorus (P) Applied per Hectare in North Carolina and Quebec

	Common Practice	Trade Scenarios		Environmental Scenarios	
		Scenario 2	Scenario 3	Nitrogen Plan	Phos-phorus Plan
	Kg per ha				
Carolina (Forage)	684 N	683.11 N	683.86 N	73 N	20 P
Quebec (Forage)	165 N	164.87 N	160.12 N	84 N	22 P
Quebec (Corn)	540 N	539.56 N	524.02 N	106 N [1]	30 P [2]

[1] Scenario 4; [2] Scenario 6

Manure Nitrogen Inserted into EPIC under Two Nutrient Management Plans

With nutrient management plans, manure applications are limited to the nutrient content that can be absorbed by the crop under cultivation. Since nutrient absorption by crops varies with nutrient input, the relationship between nutrient input and uptake by region and crop grown, is found with EPIC. The level to which crop requirements are respected (i.e. the quantity of nutrients applied per ha) is also obtained.

Figure 2 reports the results for nitrogen uptake by forage in both North Carolina and Quebec. The simulated relationship finds nutrient uptake as a function of nutrient input, given the agronomic conditions for the region included in EPIC. In Figure 2, the range of inputs for Quebec is less than for North Carolina because experimental data are unavailable to validate the Quebec results at higher input levels. In both regions, forage does not use more than 200 kg N/ha, with North Carolina having a higher absorptive capacity for inputs greater than 100 kg/ha. The solid line, at 45° (ratio of 1) indicates where the nutrient input equals uptake. Inputs beyond the intersection point of the two lines are assumed to exceed the agronomic requirements of the crop. At the intersection of the simulated and optimal crop uptakes, North Carolina and Quebec have approximately the same assimilative capacity for nitrogen.

Figure 3 shows simulation results for phosphorus application per ha of forage in North Carolina and Quebec. As in the case of absorption of nitrogen, conditions in North Carolina result in higher crop uptake of nutrients, but, where simulated and optimal uptake are equal, the absorption in the two regions is similar (20 kg for North Carolina vs. 22 kg for Quebec).

The type of crop planted, is an important determinant of nutrient uptake. Figure 4 presents the optimal and simulated relationship between inputs and absorption for nitrogen and phosphorus per ha of corn in Quebec. Recall that experimental data for Quebec include more crops and measures of water quality than in North Carolina. Data on the impact of applying manure on corn in North Carolina are not available for the area studied. Note that the model assumes a constant absorption rate multiplied by the yield.

Figure 2. Input and Absorption of Nitrogen by Forage in North Carolina and Quebec

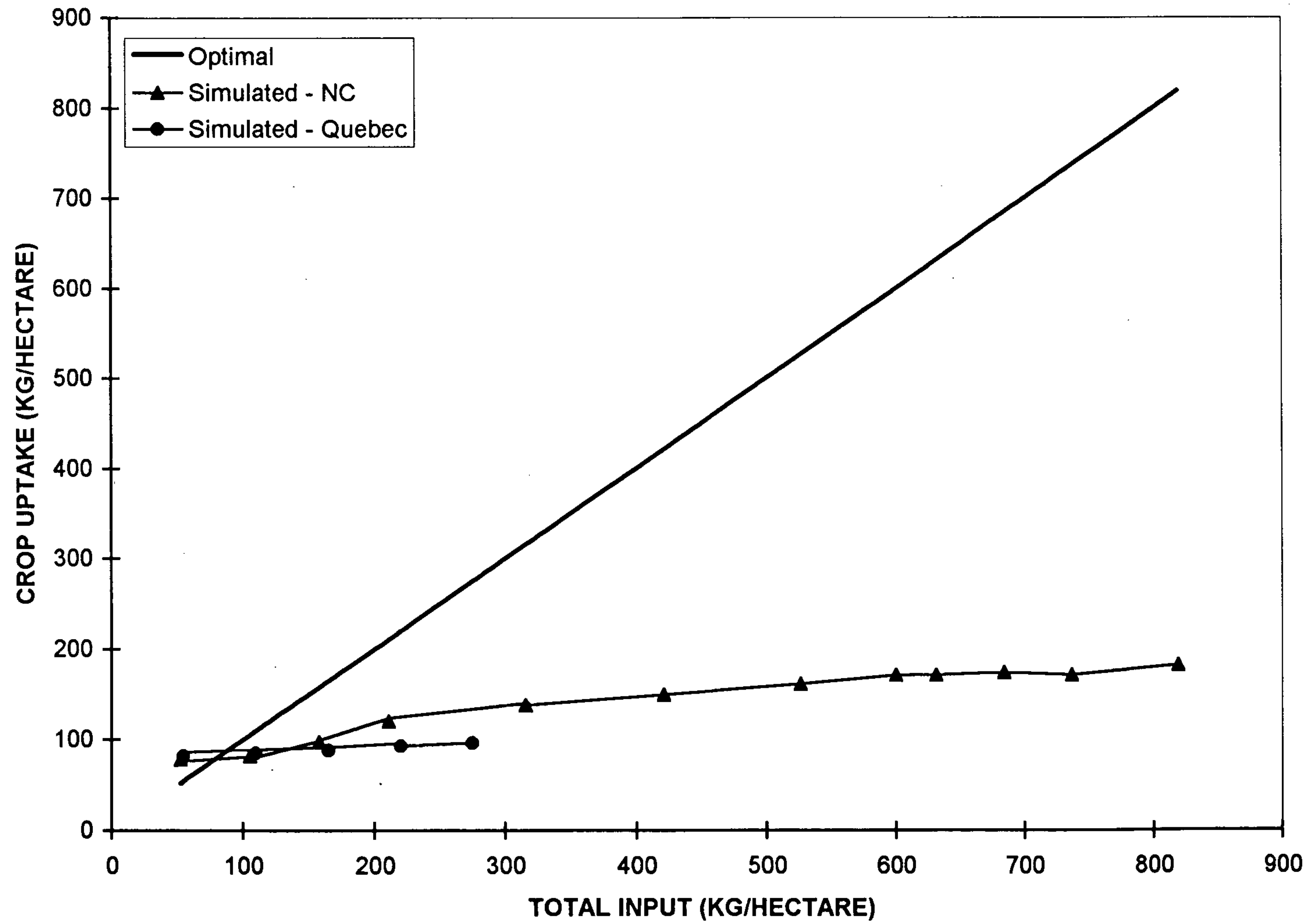


Figure 3. Input and Absorption of Phosphorus by Forage in North Carolina and Quebec

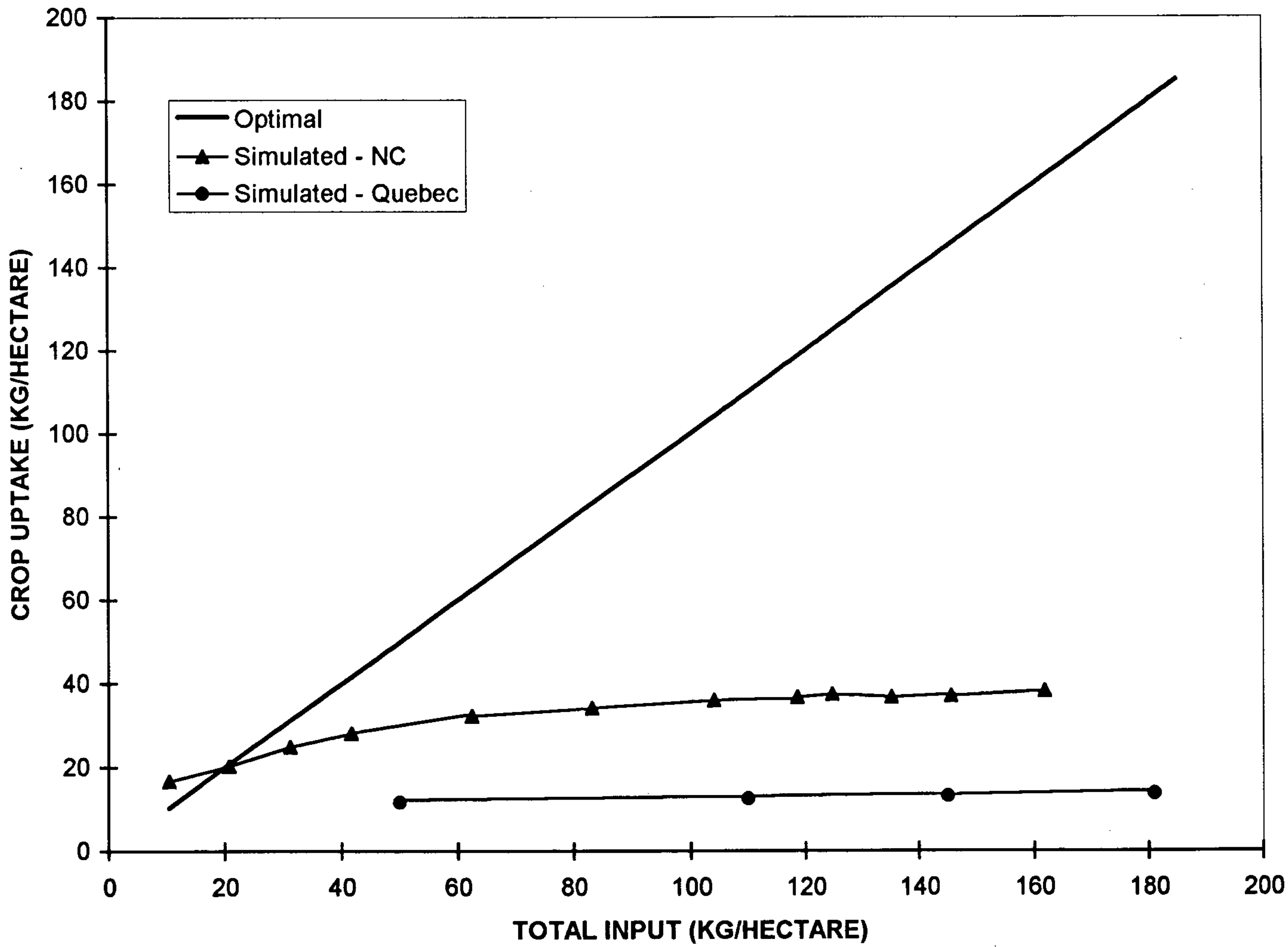
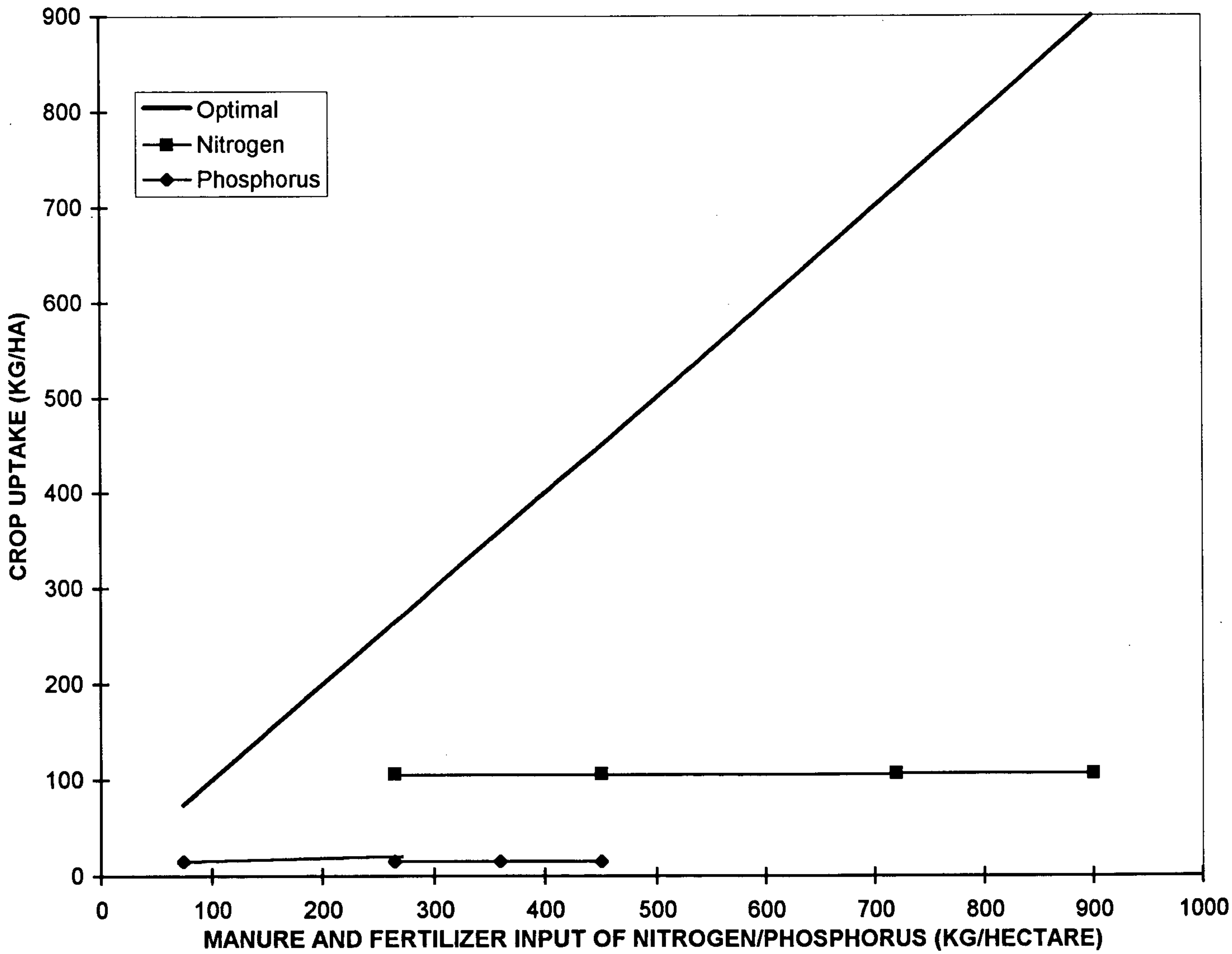


Figure 4. Input and Absorption of Nitrogen and Phosphorus by Corn in Quebec



Effect of Two Trade Scenarios and two Environmental Scenarios on Hog Management

Standards for nitrogen and phosphorus, expressed as the number of market hogs[20] per ha of land available for manure applications, are shown in Table 19. Nitrogen and phosphorus levels in Table 18 are divided by 10.44 kg and 5.22 kg respectively which are the nutrients produced annually by one hog at the finishing stage to obtain the number of hogs per hectare.

For North Carolina, the nutrient management for nitrogen would limit farmers to 7 market hogs per ha. Adding the recommendations for phosphates (allowing 3.83 hogs/ha) would introduce more stringent constraints on producers. This contrasts with commonly used levels of 65.52 hogs/ha of land used for manure applications. Since enough land is owned or rented by hog producers (1 hog/ha in the Southeast), these plans should create an incentive to spread manure on larger areas, increasing production costs.

In Quebec, manure from 34.48 market hogs is applied on each ha of corn, which would have to be decreased to 10.15 based on the nitrogen plan without chemical fertilization. Applications on forage are closer to optimal values, requiring decreases from 10.53 to 8.04 market hogs. Since the area of land owned or rented by hog producers is insufficient, the environmental

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[20]Hogs at the finishing stage equalling 0.2 animal units.

policy could necessitate the introduction of manure treatment facilities or a reduction of hog inventories.

Legislation in Quebec (Gouvernement du Québec, 1996) includes an appendix which specifies the maximum number of animal units per ha for different cultures. Maximum values correspond to 13.75 and 20.65 market hogs, when manure is applied on forage or corn respectively. This requirement is not as strict as a compulsory integrated fertilization plan which is similar to the simulated nitrogen and phosphorus plans (Table 19).

Table 19 Impact of Trade and Environmental Scenarios on Market Hogs Numbers per Hectare in North Carolina and Quebec [1]

		Trade Scenarios		Environmental Scenarios			
Region	Common Practice	2	3	Nitrogen Plan		Phosphorus Plan	
				chem. fert.	No chem. fert.	chem. fert.	No chem fert
North Carolina (Forage)	65.52	65.47	65.52	0	7	0	3.83
Quebec (Forage)	10.53 [2]	10.52	10.53	2.78	8.04	0	4.21
Quebec (Corn)	34.48 [2]	34.45	33.46	0	10.15 [3]	0	5.74 [4]

[1] number of hectares used for manure applications, assuming that the total land base is not used [2] based on 2 parts of manure for 1 part of recommended chemical (chem.) fertilizer (fert.) [3] Scenario 4; [4] Scenario 6

Effect of Two Trade Scenarios and Two Environmental Scenarios on Water Quality

Figures 5, 6 and 7 show the mass transport of nutrients as a function of inputs for North Carolina and Quebec. The results permit a comparison of the amount of nutrients in runoff and/or leachate, resulting from 1) commonly applied inputs and 2) the inputs under nutrient plans with 3) inputs following trade liberalization.

These three figures show that releases of nutrients are not equal to zero at optimal input levels where input equals average crop uptake. Different factors, like climate and accumulation of nutrients in the soil, affect the crop uptake and make it deviate from the uptake estimated for average conditions inducing nutrient losses in the environment. For example, if the temperature is colder than usual and if phosphorus is being accumulated at a high rate in the soil, the uptake is less than the uptake estimated for average conditions. Furthermore, there are nutrient losses in the environment even without any human intervention.

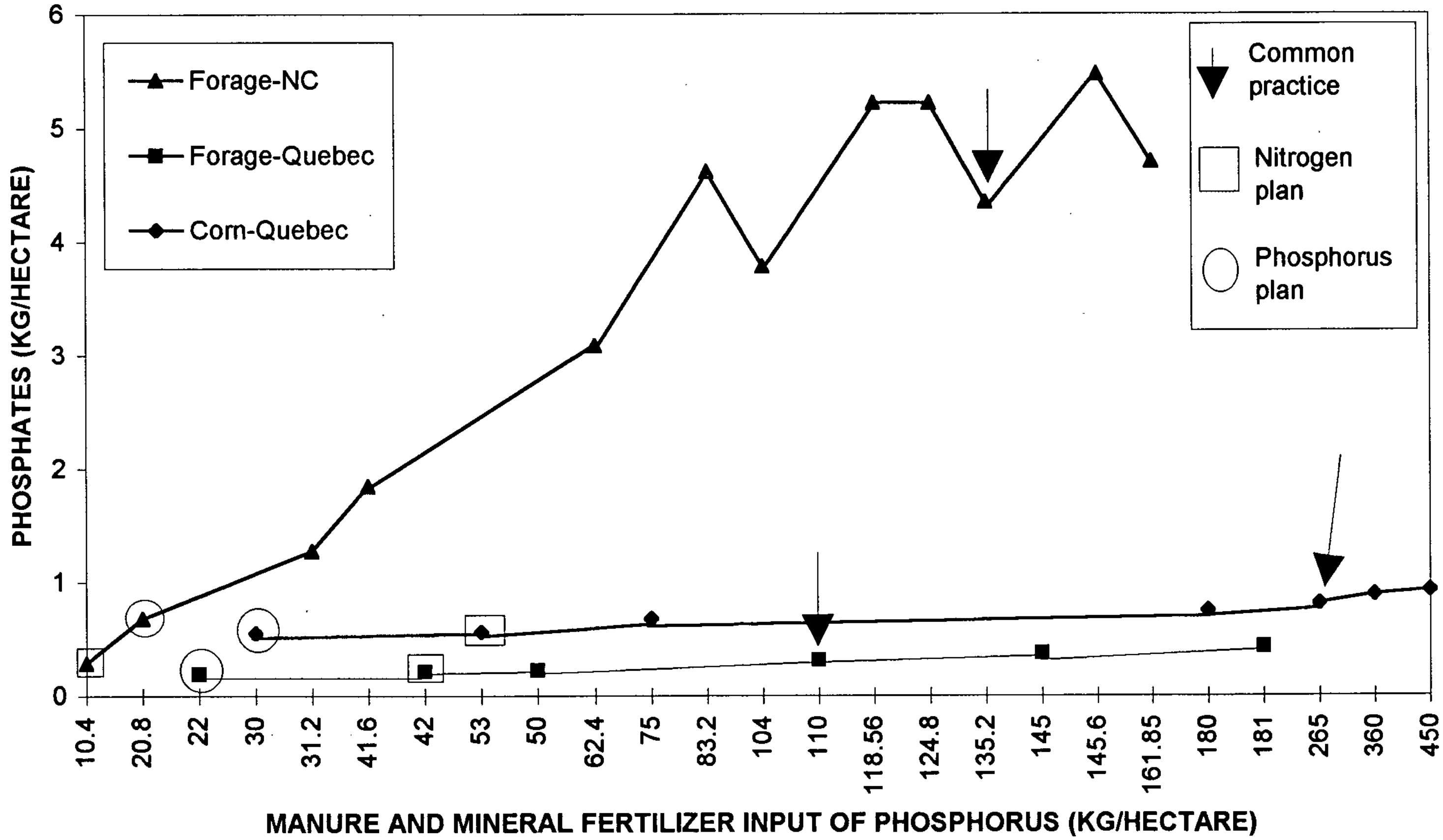
Losses of phosphates are significantly more important in North Carolina than in Quebec (Figure 5). Quantities of phosphates in runoff, move up and down when more than 100 kg P/ha is applied, since applications beyond a critical point can cause imbalances in the ecosystem. Impacts of output changes on water quality cannot be predicted in that range. In Quebec, more phosphates are present in runoff when corn is cultivated than when forage provides a full cover to the soil.

Like losses of phosphates, losses of nitrates in runoff are larger in North Carolina than in Quebec (Figure 6). The relationship between the amount of nitrogen applied, to the nitrates in runoff, increases at every input level (except for a brief pause at 600 kg/ha). The runoff curve for Quebec is almost flat until applications of 165 kg/ha begin, where the curve rises slightly, compared to more pronounced changes in output observed in the leaching curve.

The forage leaching curve is nonlinear. The level of nitrates is lower, with 84 kg/ha derived from manure than with 55 kg/ha from mineral fertilizer, since only 60% of the manure nitrogen (50.4 kg/ha) is available during the first year (Gouvernement du Québec, 1995). The curve kinks upward when the input is higher than 165 kg/ha, the amount which is commonly applied. Changes could appear less abrupt if more data points were used; nevertheless, any inventory increases due to trade liberalization would have noticeable effects on nitrates in drainage when manure is applied on forage.

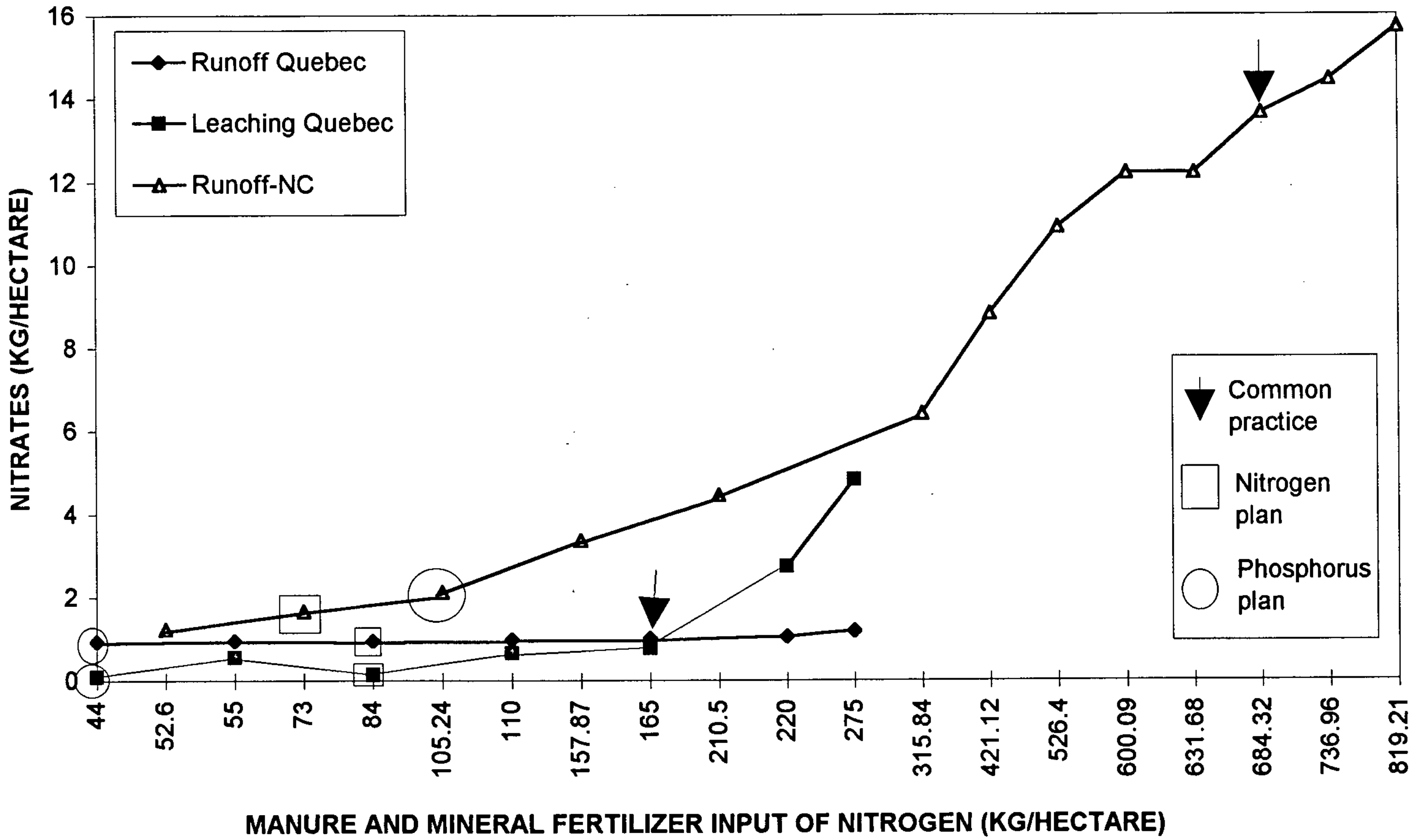
The level of nitrates in runoff and leaching in Quebec, when corn is cultivated is shown on Figure 7. The phenomena in these situations are similar to those observed in forage cover, but at a different scale. The leaching of nitrates range from 12 to 100 as opposed to 0.09 to 5 kg/ha (on forage). Again, the quantity of nitrates in leaching rises noticeably after the application of 180 kg N/ha, and the runoff curve is flatter than the leaching curve.

Figure 5. Impact of Land Application of Swine Lagoon Effluent on Mass Transport of Phosphates in Runoff in North Carolina and Quebec



Nitrogen and Phosphorus Plans: Nutrient management plans according to crop agronomic requirements with respect to nitrogen and phosphorus

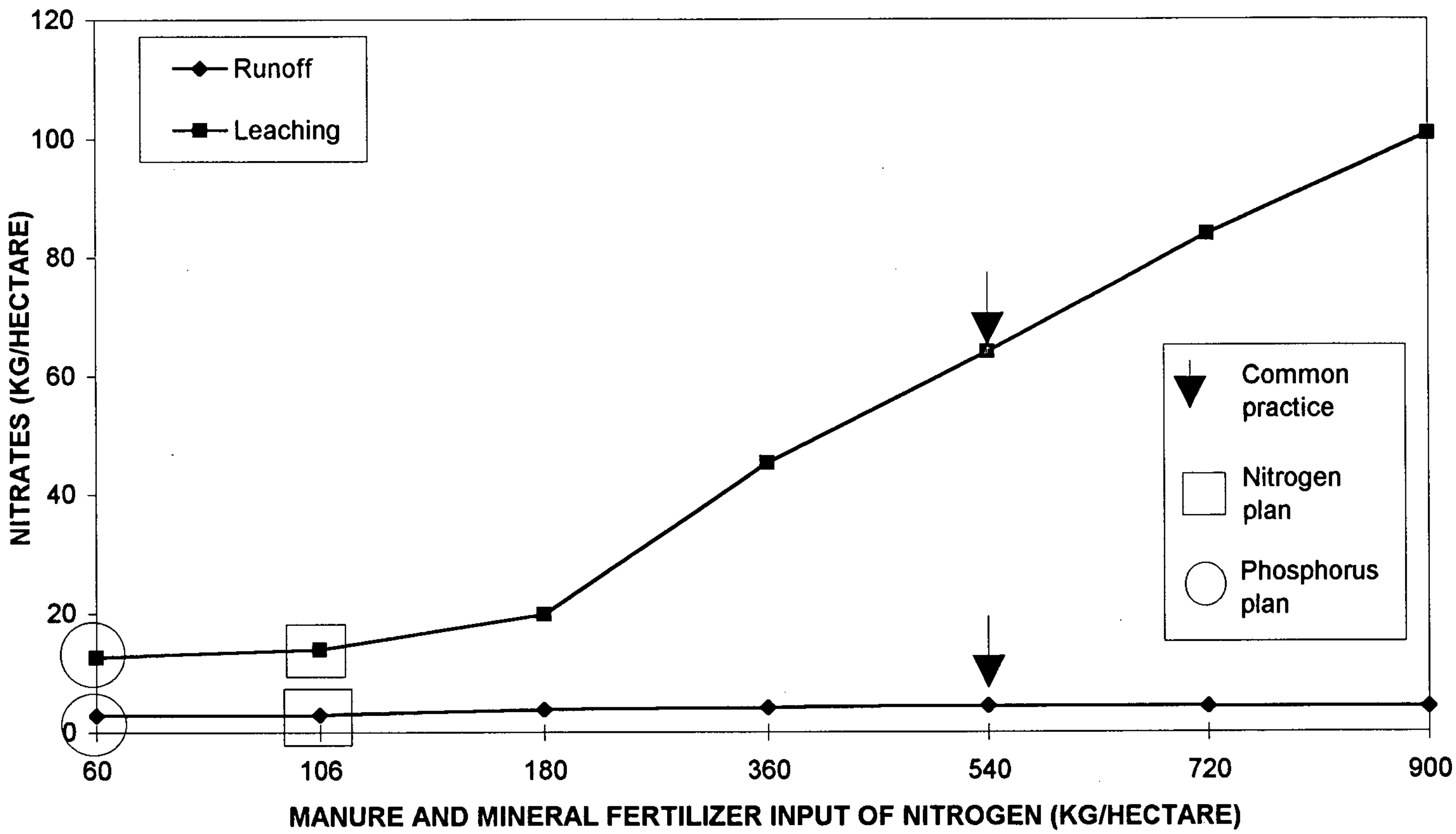
Figure 6. Impact of Land Application of Swine Lagoon Effluent on Forage on Mass Transport of Nitrates in North Carolina and Quebec



All treatments in Quebec include 55 kg of mineral fertilizer except the 44 and 84 kg inputs

Nitrogen and Phosphorus Plans: Nutrient management plans according to crop agronomic requirements with respect to nitrogen and phosphorus

Figure 7. Impact of Land Application of Swine Lagoon Effluent on Corn on Mass Transport of Nitrates in Runoff and in Leaching in Quebec



Nitrogen and Phosphorus Plans: Nutrient management plans according to crop agronomic requirements with respect to nitrogen and phosphorus

Results for levels of nutrients corresponding to different scenarios are summarized in Table 20 for North Carolina and in Table 21 for Quebec. First, these results compare environmental scenarios among themselves and these comparisons avoid the uncertainty related to the choice of a baseline. Second, comparisons between the nitrogen and phosphorus plans, and the baseline, are used to assess the impact of environmental scenarios.

Regarding North Carolina, Table 20 shows that the phosphorus plan recommends manure applications according to crop agronomic requirements which bring the levels of phosphates and nitrates to higher levels than with the nitrogen plan. This conclusion depends on the assumption adopted for the nitrogen-phosphorus ratio. The nitrogen-phosphorus ratio, which is observed in the slurry sprayed on the field after lagoon treatment and volatilization (Burns *et al.,* 1987), ranges from 5:1 to 8:1. Hence, the ideal crop input of 20 kg of phosphorus, according to the phosphorus plan, corresponds to at least 100 kg of nitrogen, which is more than that recommended under the nitrogen plan (73 kg of nitrogen). A nitrogen-phosphorus ratio of 5:1 is chosen since the focus in this section is on the dose of nutrients applied to soil having impacts on water quality; not on the total amount of nutrients released in the environment having impacts on air and water quality.

Both plans decrease the levels of nitrates and phosphates in runoff by at least 80% compared to the actual runoff. In

North Carolina, the effect of trade liberalization on inventories is too small to have any impact on water quality, and hence does not change the net effect of trade and environmental policies (Table 20).

Table 20 Impact of Trade and Environmental Scenarios on Water Quality in North Carolina [1]

Nutrients in Runoff	Common Practice	Scenario 2	Scenario 3	Nitrogen Plan	Phosphorus Plan
	Kg/Ha of Nutrients in Runoff				
Phosphates (forage)	4.34	4.34 (0)	4.34 (0)	0.51 (-80.25)	0.73 (-83.18)
Nitrates (forage)	13.64	13.64 (0)	13.64 (0)	1.66 (-87.83)	2.11 (-84.53)

[1] Percentage changes from the common practice are in parenthesis.

As opposed to the findings in North Carolina, the phosphorus plan in Quebec is more stringent than the nitrogen plan, but the impacts of the phosphorus and nitrogen plans differ by no more than 5%. Following the implementation of these policies, improvements in groundwater quality should be more obvious than improvements in surface water quality. Decreases in the level of nitrates in leachate vary from 79% to 88%, while levels of nitrates in runoff drop by 6% to 35%. Similarly the levels of phosphates in runoff drop by 31 to 39% when both plans are in force.

In Quebec, removal of the hog countervailing duty and stabilization payments have no impact on water quality, but withdrawal of the nontariff barrier (scenario 3) improves water quality. Through changes in hog inventories, the nontariff barrier decreases the level of nitrates while leaving the level of phosphates unchanged.

Removal of the hog countervailing duty could worsen the environmental conditions in Ontario and Western Canada since this trade policy triggers a small increase in inventories of 0.22% and 0.7%, respectively (Table 22). Increases in inventories within these regions, rather than in Quebec or the Atlantic provinces, are not surprising since Ontario and Western Canada exported 97.9% of all Canadian live hog exports during the study period.

Even if international trade is expected to be a minor contributor to water quality deterioration in Ontario and Western Canada and does not appear to contribute to pollution in the two cases studied in Quebec and North Carolina, surface water flowing through some Quebec agricultural areas is of mediocre quality (Primeau and Grimard cited in Ganbazo, 1995) and North Carolina is the seventh most sensitive US state to nitrogen fertilizer leaching (Kellogg *et al.*, 1994). To improve water quality, proper environmental policy like the nutrient plans discussed earlier, are more appropriate than trade protection.

The timing of land applications has no qualitative effect on conclusions, but has an impact on the absolute levels of nutrient loss. In the data reported above, optimal inputs are applied only in the spring. Dividing quantities between spring and fall applications increases all nutrient losses except the level of nitrates in drainage under the nitrogen plan. Nitrates in runoff rise from 2.85 to 2.99 kg/ha and the levels of nitrates in leachate rise from 13.42 to 14.38 kg/ha when corn is cultivated.

Table 21 Impact of Trade and Environmental Scenarios on Water Quality in Quebec [1]

		Trade Scenarios		Environmental Scenarios	
Nutrients in Runoff and in Drainage	Common Practice	2	3	Nitrogen Plan	Phosphorus Plan
	Kg/Ha of Nutrients				
Phosphates in Runoff (forage)	0.31	0.31	0.31	0.21 (-32.26)	0.19 (-38.71)
Phosphates in Runoff (corn)	0.81	0.81	0.81	0.56 (-30.86) [2]	0.56 (-30.86) [3]
Nitrates in Runoff (forage)	1	1	0.99 (-1)	0.94 (-6)	0.93 (-7)
Nitrates in Runoff (corn)	4.35	4.35	4.32 (-0.69)	2.85 (-34.48) [2]	2.79 (-35.86) [3]
Nitrates in Drainage (forage)	0.77	0.77	0.76 (-1.3)	0.13 (-83.12)	0.09 (-88.31)
Nitrates in Drainage (corn)	63.99	63.9 9	62.34 (-2.58)	13.42 (-79.03) [2]	12.59 (-80.33) [3]

[1] Percentage changes from the common practice are in parenthesis [2] Scenario 4 [3] Scenario 6

Typically, North American trade liberalization schemes within US and Canadian agricultural industries cause small effects on price and output. Alternative trade liberalization scenarios, like increases in exports to Mexico, following phasing-out a 20% tariff under the North American Free Trade Agreement (NAFTA), could have a greater impact than the elimination of countervailing duties.

Effect of Nine Trade and Environmental Scenarios on Welfare, Trade, Hog Inventories and Slaughter Amounts

Effects on welfare, hog inventories and slaughter amounts, obtained from the economic model, are presented in Table 22, for trade liberalization scenarios, and in Table 23 for environmental scenarios. For all scenarios, welfare is reported for a six-year period for two US regions, corresponding to the two US-producing regions and four Canadian regions. Regional welfare in the Southeast is the area under the demand curves for the East and South, minus the costs in the Northeast and South SPS minus farm costs in the Southeast. Regional welfare in the Midwest and Western US is the area under the demand curves of the Midwest and West, minus costs in the Midwest and Western SPS, minus farm costs in the Midwest. The costs of pork, slaughtered in the Midwest and exported to the Southern demand market, are incorporated in the Midwest and Western US welfare. Since Canadian regions are the same at the demand, SPS, and production levels, the welfare calculation is the area under each region's demand curve, minus all costs.

Table 22 Market Welfare, Hog Inventories, Slaughter Amounts, Live Hog and Pork Exports and Percentage Difference from the Baseline for Three Trade Scenarios [1]

Regions	Scenarios			
	Baseline	1	2	3
Total Welfare 1987-1992 in US$ Million				
North America	54747.06	54746.84 (0)	54747.03 (0)	54810.88 (0.12)
United States	38728.07	38730.86 (0.01)	38731.5 (0.01)	38921.43 (0.5)
East & South US	25938.08	25939.86 (0.01)	25942.96 (0.02)	25962.94 (0.1)
Midwest & West US	12789.08	12791.01 (0.02)	12788.54 (0)	12958.49 (1.32)
Canada	16018.99	16015.98 (-0.02)	16015.53 (-0.02)	15889.45 (-0.81)
Atlantic	1586.53	1586.82 (0.02)	1587.23 (0.04)	1589.5 (0.19)
Quebec	4161.49	4161.57 (0)	4171.33 (0.24)	4135.32 (-0.63)
Ontario	5764.1	5765.48 (0.02)	5754.95 (-0.16)	5662.53 (-1.76)
Western Canada	4506.88	4502.1 (-0.11)	4502.01 (-0.11)	4502.11 (-0.11)
Average Hog Inventories in Million Head				
North America	73.89	73.89 (0)	73.89 (0)	73.71 (-0.24)
US	64.772	64.75 (-0.03)	64.75 (-0.03)	64.71 (-0.1)
Southeast	8.05	8.05 (0)	8.04 (-0.12)	8.05 (0)
Midwest	56.72	56.71 (-0.02)	56.71 (-0.02)	56.66 (-0.11)
Canada	9.12	9.14 (0.22)	9.15 (0.33)	9 (-1.32)

Table 22, continued

Regions	Scenarios			
	Baseline	1	2	3
Atlantic	0.33	0.33 (0)	0.33 (0)	0.32 (3.03)
Quebec	2.51	2.51 (0)	2.51 (0)	2.44 (-2.79)
Ontario	2.83	2.83 (0)	2.84 (0.35)	2.77 (-2.12)
Western Canada	3.45	3.47 (0.58)	3.47 (0.58)	3.47 (0.58)
Average Slaughter Levels in Million Cwt				
North America	46.44	46.44 (0)	46.47 (0.06)	46.39 (-0.11)
US	40.54	40.55 (0.02)	40.56 (0.05)	39.21 (-3.28)
Northeast	3.92	3.91 (-0.26)	3.9 (-0.51)	3.92 (0)
South	9.93	9.93 (0)	9.94 (0.1)	9.83 (-1.01)
Midwest	25.69	25.7 (0.04)	25.71 (0.08)	24.45 (-4.83)
West	1.01	1 (-0.99)	1.01 (0)	1.02 (0.99)
Canada	5.9	5.89 (-0.17)	5.89 (-0.17)	7.18 (21.69)
Atlantic	0.22	0.22 (0)	0.22 (0)	0.22 (0)
Quebec	1.68	1.68 (0)	1.59 (-5.36)	1.98 (17.86)
Ontario	1.68	1.67 (-0.6)	1.75 (4.17)	2.67 (58.93)
Western Canada	2.32	2.33 (0.43)	2.33 (0.43)	2.31 (-0.43)

Table 22, continued

Regions	Scenarios			
	Baseline	1	2	3
Total Live Hog Exports 1987-1992 in Million Head				
US to Canada	0	0	0	91.5
Canada to US	4.01	4.04 (0.75)	4.71 (17.46)	1.5 (-62.62)
Total Pork Exports from SPS to Demand Sector, 1987-1992 in Million Cwt				
US to Canada	30.6	30.8 (0.92)	30.88 (0.92)	8.45 (-72.39)
Canada to US	4.75	4.90 (3.16)	4.89 (2.95)	6.19 (30.32)

[1] Percentage differences from baseline are in parenthesis

Table 23 Market Welfare, Hog Inventories, Slaughter Amounts, Live Hog and Pork Exports and Percentage Difference from the Baseline for Six Environmental Scenarios [1]

Regions	Scenarios		
	4	5	6
	Total Welfare 1987-1992 in US$ Million		
North America	53992.78 (-1.38)	54761.68 (0.03)	53517.73 (-2.25)
United States	37976.58 (-1.94)	38661.67 (-0.17)	37556.5 (-3.03)
East & South	25768.96 (-0.65)	26014.41 (-0.29)	25560.95 (-1.45)
Midwest & West	12207.63 (-4.55)	12647.26 (-1.11)	11995.55 (-6.2)
Canada	16016.2 (-0.02)	16100.01 (0.51)	15961.24 (-0.36)
Atlantic	1581.47 (-0.32)	1585.03 (-0.09)	1583.34 (-0.2)
Quebec	4240.22 (1.89)	4242.37 (1.94)	4369.06 (4.99)
Ontario	5720.79 (-0.75)	5755.84 (-0.14)	5543.30 (-3.83)
Western Canada	4472.72 (-0.76)	4516.77 (0.22)	4465.53 (-0.92)
	Average Hog Inventories in Million Head		
North America	73.36 (-0.72)	74.13 (0.32)	72.87 (-1.38)
US	64.86 (0.14)	65.62 (1.31)	64.96 (0.3)
Southeast	8.03 (-0.25)	8.15 (1.24)	8.01 (-0.5)
Midwest	56.83 (0.19)	57.47 (1.32)	56.95 (0.41)
Canada	8.5 (-6.8)	8.51 (-6.69)	7.91 (-13.27)
Atlantic	0.33 (0)	0.33 (0)	0.33 (0)

Table 23, continued

Regions	Scenarios		
	4	5	6
Average Hog Inventories in Million Head			
Quebec	1.87 (-25.5)	1.87 (-25.5)	0.68 (-72.91)
Ontario	2.85 (0.71)	2.86 (1.06)	3.46 (22.26)
Western Canada	3.44 (-0.29)	3.44 (-0.29)	3.45 (0)
Average Slaughter Levels in Million Cwt			
North America	46.03 (-0.88)	46.51 (0.15)	45.61 (-1.79)
US	40.32 (-0.55)	40.85 (0.76)	40.18 (-0.89)
Northeast	3.9 (-0.43)	3.88 (-1.02)	3.89 (-0.77)
South	9.87 (-0.65)	9.82 (-1.14)	9.8 (-1.31)
Midwest	25.57 (-0.46)	26.16 (1.86)	25.51 (-0.68)
West	0.98 (-2.53)	0.99 (-1.87)	0.98 (-2.69)
Canada	5.71 (-3.24)	5.66 (-3.99)	5.43 (-8)
Atlantic	0.23 (0.93)	0.23 (1.41)	0.22 (0)
Quebec	1.56 (-7.3)	1.56 (-6.8)	1.37 (-18.45)
Ontario	1.64 (-2.27)	1.62 (-3.19)	1.53 (-8.93)
Western Canada	2.29 (-1.4)	2.25 (-3.05)	2.31 (-0.43)

Table 23, continued

Regions	Scenarios		
	4	5	6
Total Live Hog Exports 1987-1992 in Million Head			
US to Canada	0	0	0
Canada to US	3.35 (-16.46)	2.96 (-26.18)	3.26 (-18.7)
Total Pork Exports from SPS to Demand Sector, 1987-1992 in Million Cwt			
US to Canada	32.43 (5.98)	33.41 (9.18)	36.74 (20.07)
Canada to US	4.71 (-0.84)	4.69 (-1.26)	4.71 (-0.84)

[1] Percentage differences from baseline are in parenthesis

Table 23, continued

Regions	Scenarios		
	7	8	9
Total Welfare 1987-1992 in US$ Million			
North America	54294.59 (-0.83)	46058.78 (-15.87)	48022.59 (-12.28)
United States	38252.46 (-1.23)	31034.78 (-19.86)	33094.53 (-14.55)
East & South	25817.99 (-0.46)	21655.21 (-16.51)	22479.21 (-13.34)
Midwest & West	12434.46 (-2.77)	9379.56 (-26.66)	10615.32 (-17)
Canada	16042.13 (0.14)	15024 (-6.21)	14928.07 (-6.81)
Atlantic	1587.2 (0.04)	1568.59 (-1.13)	1571.52 (-0.95)
Quebec	4370.97 (5.03)	3948.67 (-5.11)	3937.3 (-5.39)
Ontario	5577.81 (-3.23)	5516.85 (-4.29)	5261.09 (-8.73)
Western Canada	4506.14 (-0.02)	3989.89 (-11.47)	4158.15 (-7.74)
Average Hog Inventories in Million Head			
North America	73.65 (-0.32)	56.55 (-23.47)	52.81 (-28.52)
US	65.73 (1.48)	48.37 (-25.32)	45.32 (-30.03)
Southeast	8.07 (0.25)	6.67 (-17.14)	6.03 (-25.06)
Midwest	57.66 (1.66)	41.7 (-26.48)	39.29 (-30.73)
Canada	7.93 (-13.05)	8.17 (-10.35)	7.49 (-17.82)
Atlantic	0.33 (0)	0.19 (-40.48)	0.19 (-41.14)

Table 23, continued

Regions	Scenarios		
	7	8	9
Average Hog Inventories in Million Head			
Quebec	0.68 (-72.91)	2.13 (-15.37)	2.11 (-15.9)
Ontario	3.48 (22.98)	2.45 (-13.5)	2.29 (-19.14)
Western Canada	3.45 (0)	3.41 (-1.26)	2.9 (-15.94)
Average Slaughter Levels in Million Cwt			
North America	46.1 (-0.74)	35.01 (-24.62)	36.47 (-21.47)
US	40.65 (0.27)	30.38 (-25.06)	29.56 (-27.84)
Northeast	3.88 (-0.94)	3.2 (-18.45)	3.33 (-15.16)
South	9.74 (-1.93)	4.36 (-56.11)	4.36 (-56.11)
Midwest	26.05 (1.4)	22.73 (-11.53)	21.47 (-16.4)
West	0.98 (-2.39)	0.11 (-89.71)	0.1 (-90.26)
Canada	5.45 (-7.63)	4.62 (-21.63)	7.22 (22.37)
Atlantic	0.22 (-3.67)	0.15 (-32.88)	0.18 (-19.15)
Quebec	1.38 (-17.71)	1.23 (-26.77)	1.54 (-8.03)
Ontario	1.55 (-7.61)	0.67 (-59.99)	2.77 (65.23)
Western Canada	2.3 (-0.73)	2.57 (10.91)	2.72 (17.35)

Table 23, continued

Regions	Scenarios		
	7	8	9
Total Live Hog Exports 1987-1992 in Million Head			
US to Canada	0	0	64.78
Canada to US	3.24 (-19.2)	0.21 (-94.76)	0.32 (-92.02)
Total Pork Exports from SPS to Demand Sector, 1987-1992 in Million Cwt			
US to Canada	36.64 (19.74)	46.44 (51.76)	10.53 (-65.59)
Canada to US	4.68 (-1.47)	10.69 (125)	17.81 (275)

[1] Percentage differences from baseline are in parenthesis

Results in Table 22 are discussed separately for scenarios simulating the abolition of countervailing duties (scenarios 1 and 2) and for the elimination of the ban on US live hog exports to Canada (scenario 3). Likewise, results in Table 23 are discussed separately for the multilateral implementation of nutrient management plans (scenarios 4 and 6), the unilateral implementation of nutrient plans in Quebec (scenarios 5 and 7) and the multilateral implementation of a moratorium under actual and free trade conditions (scenarios 8 and 9).

Scenarios 1 and 2

Canadian exports of pork increase by 3.16% following the removal of the pork countervailing duty (scenario 1, Table 22). These increases can be attributed to increased pork exports from Western Canada to the Western US (4.46%). Inventories and average slaughter levels increase by 0.58% and 0.43% in Western Canada and prices in the Midwest decrease by 0.01%. Increased trade and decreased prices in the importing country are in accordance with theory.

In scenario 2, the removal of the hog countervailing duty and the stabilization payments (once the pork countervailing duty is removed) brings Canadian hog exports to 4.71 million head, a 17.46% increase from the baseline. Exports from Ontario increase by 42%, while exports from Western Canada increase by 8%. If the countervailing duty were offsetting production subsidies, the net effect of removing both the duty and the subsidies should be negligible. Either countervailing duties are higher than the optimal duties and/or the impact of stabilization payments on production decisions are improperly modelled. According to Moschini and Meilke (1993), the former is true: the estimated countervailing duties to restore equilibrium are positive but significantly less than the unit production subsidy on hogs and pork. To date, the actual hog countervailing duty, which is an input in the model, has been equal to the unit production subsidy.

Welfare impacts from trade flow modifications are small and local: North American welfare does not change.

Scenario 3

According to the third scenario where the nontariff barrier is removed, live hog exports from the Midwest to Quebec and Ontario, presently forbidden, flood the market. US exports to Canada over the six-year period reach 91 million head while exports of pork decrease from 30.88 to 8.45 million cwt. Live hog exports from Canada to the US decrease by 63%, from 4.01 to 1.5 million head. As a consequence, slaughter increases by 21.7% in Canada and decreases by 3.28% in the US.

North American market welfare increases by 0.12% following the removal of the nontariff barrier which is the trade policy scenario with the most significant impact. Regional welfare percentage differences are at the most 1.76%, in the first three scenarios. Decreases in inventories are partly compensated by pork price increases and consumer and producer effects offset each other.

Scenarios 4 and 6

The fourth and sixth scenarios restrict Quebec inventories to 96% and 35% of 1987 inventories, and increase costs in other regions in accordance with the nitrogen and phosphorus plans. These plans cause reductions of 25% and 73% of Quebec inventories. To fill the gap between production and demand, Ontario inventories increase by 0.71% and 22% in scenarios 4 and 6. Despite this adjustment, Canadian pork production decreases by 3% and 8%.

Quebec is the only region where welfare increases; hog prices increase by 0.74% and 5.43% (scenarios 4 and 6 respectively) following inventory restrictions.

Scenarios 5 and 7

Scenarios 5 and 7 simulate unilateral environmental policies in Quebec. These scenarios are equivalent to scenarios 4 and 6, but without increased costs in regions outside of Quebec.

Lenient environmental policies in other regions could be interpreted as a disguised subsidy triggering an increase in production. If this were the case, representatives from the Quebec hog/pork industry could argue in favor of a compensation from the Quebec Government.

Comparisons Between Scenarios 4 and 5, and 6 and 7

As expected, inventories in regions outside of Quebec are increased (by about 1%) by the elimination of additional costs related to manure applications on larger areas (scenarios 5 and 7 vs. scenarios 4 and 6). The results show that increased production costs due to environmental regulations in one region reduce competitiveness. In the long run, and not included in the model, firms can successfully adopt alternative technologies which may offset early cost disadvantages.

Scenarios 8 and 9

Scenarios 8 and 9 simulate implementing a moratorium across North America on 1987 inventory levels under actual and free trade conditions. In scenario 8, North American inventories decrease by 23% and welfare decreases by 16% to the lowest value measured among the 9 scenarios. The decrease in inventories for Quebec is less than in scenario 4 which is consistent, since the restrictions in scenario 8 are not as stringent as in scenario 4.

In scenario 9, US pork exports are partly substituted by live hog exports as in the third scenario. These live hogs are processed mainly in Ontario and Western Canada.

Trade Patterns Across Scenarios

In the previous section, trade patterns were discussed with welfare, inventory, and slaughter changes. Figures 8 and 9 compare live hog and pork trade patterns across the nine scenarios. As can be seen in the baseline in Figure 9, pork flows both ways across the Canada/US border since trade is regional. Pork is traded simultaneously between Western Canada and the Midwest and between Eastern Canada and the Eastern US.

In scenarios 3 and 9, where the ban on US live hog exports to Canada is lifted, US live hog exports increase at the expense of US pork exports. Canadian live hog exports to the US also decrease significantly (63% and 95% in scenarios 3 and 9, respectively). In scenario 8 (moratorium), live hog trade virtually disappears (to 0.21 million head), while US pork exports to Canada increase by 52%, and Canadian pork exports to the US increase by 125%.

Furthermore, in scenarios 4 to 7, restrictions on Quebec inventories have a significant impact on trade patterns. Live hog trade from Canada to the US decreases between 16% and 26%. In the four scenarios, exports of 487,000 hogs from Quebec to the Eastern US, come to an end, and exports from Ontario decrease by up to 41%. Exports from Western Canada to the Western US increase by up to 24% which does not compensate for the losses from Ontario and Quebec to the US. Net exports of live hogs from Ontario to Quebec increase from 338,000 head to more than 5.5 million head.

In the four scenarios, US pork exports to Canada increase by 6% to 20%. In scenarios 4 and 5, US pork exports to Canada increase by 6% and 9% while exports to Ontario increase by 10%. Exports from the Midwest to Western Canada, which increase from 29% to 76%, are responsible for the difference between scenarios 4 and 5. In scenarios 6 and 7, US pork exports to Canada increase by about 20% while exports to Ontario are 18% higher than the baseline. Exports to Quebec jump by 75% and 82% from the baseline. This is understandable since Quebec inventories are 73% lower than the baseline due to restrictions on inventories.

Figure 8. Sum of Live Hog Exports from 1987 to 1992 under the Baseline and Alternative Scenarios

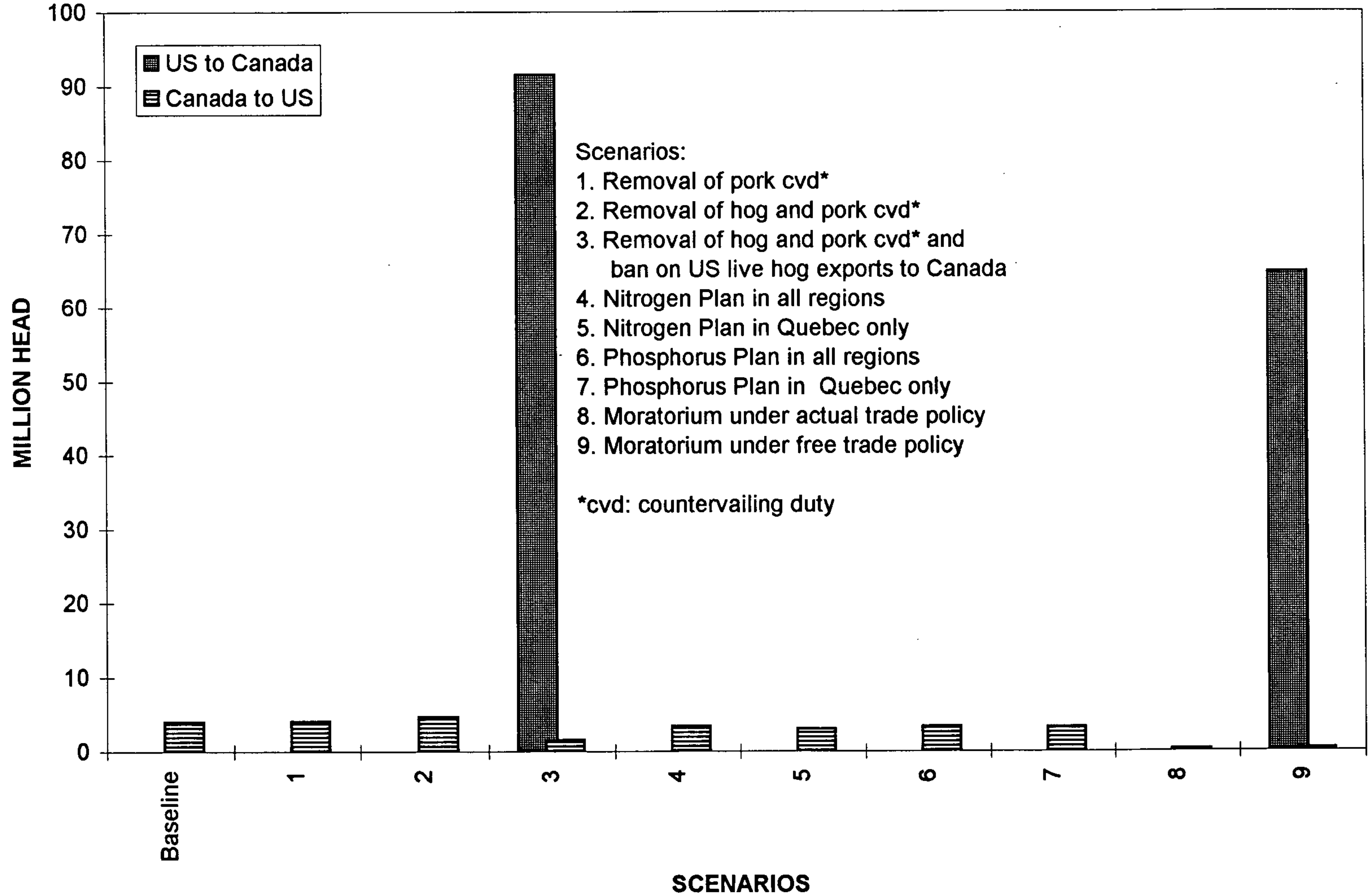
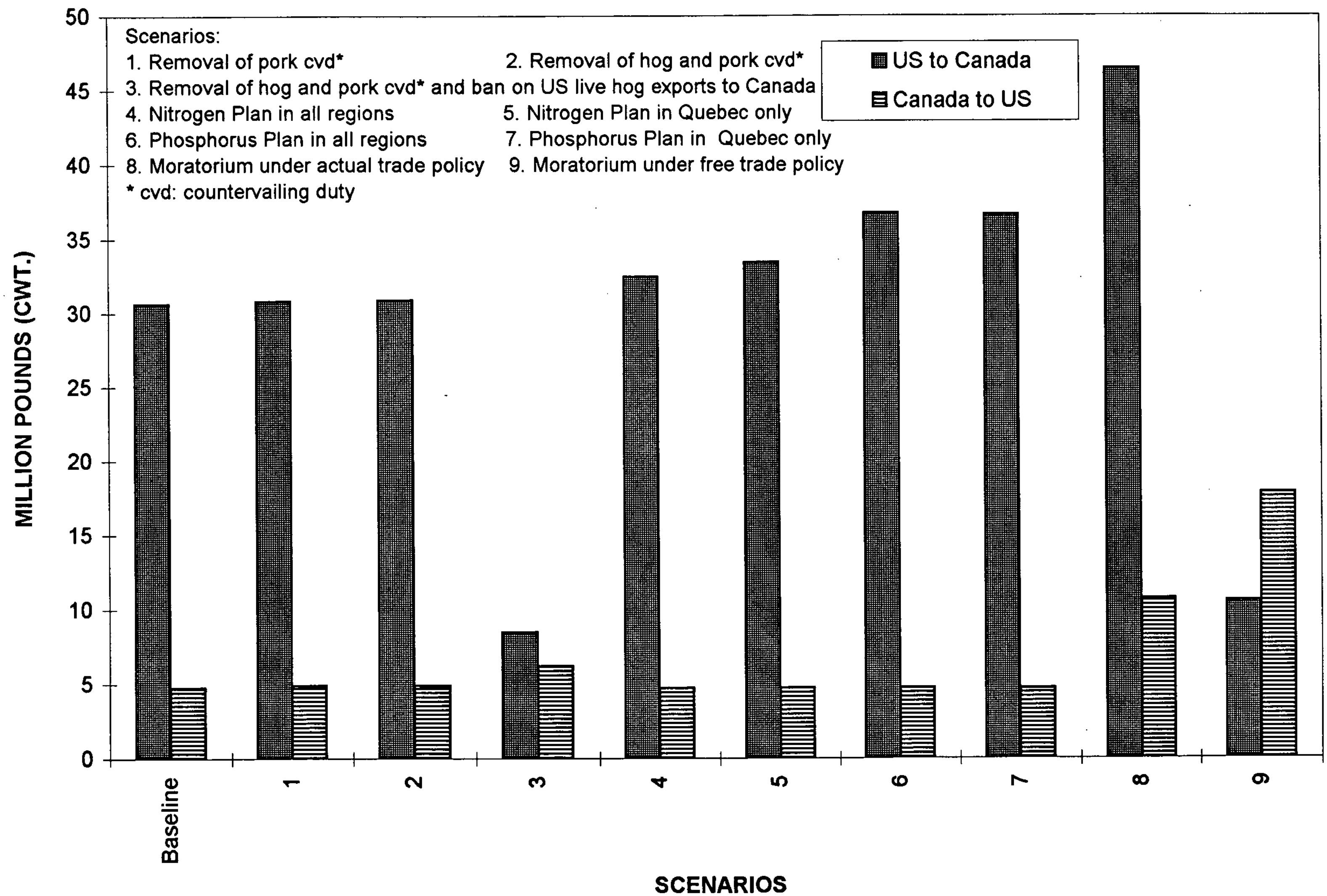


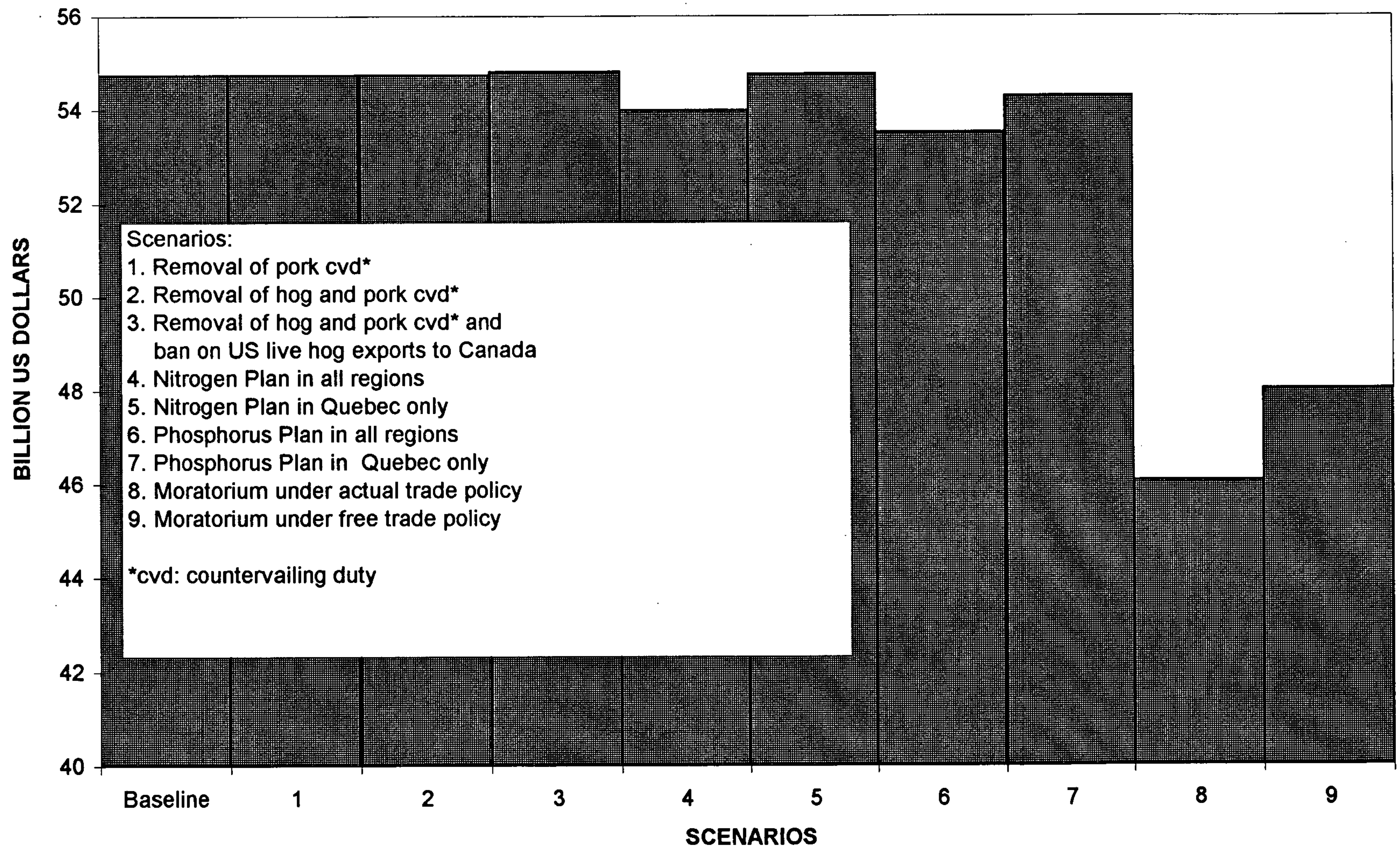
Figure 9. Sum of Pork Exports from 1987 to 1992 under the Baseline and Alternative Scenarios



North American Welfare Changes Across Scenarios

While trade liberalization scenarios have little impact on North American welfare (Figure 10), environmental scenarios trigger decreases in market welfare. As expected, decreases are less important when environmental policy is applied unilaterally in Quebec than when policies are applied in all regions because lower costs are entered in the objective function (scenarios 7 vs. 6). A moratorium across North America brings about a decrease of almost 16%, North American inventories being 23% below the baseline level (scenario 8). The impact on welfare of a moratorium is tempered under free trade conditions since trade flows are optimal when unconstrained (scenario 9).

Figure 10. North American Welfare from 1987 to 1992 under the Baseline and Alternative Scenarios



Regional Market Welfare Versus Environmental Impacts

Since welfare measures are calculated at the regional level, and water quality occurs at the local level, the trends rather than the magnitudes of water quality and welfare changes, are compared to determine if economic and environmental objectives conflict. Increases and decreases in market welfare and water quality are indicated as + and -, respectively (Table 24) for the four scenarios simulated with the economic and environmental models.

Table 24 Water Quality and Market Welfare Changes in North Carolina and Quebec

Location		Scenarios			
		2	3	4	6
Southeast	Market Welfare	+	+	**-**	**-**
Raleigh, North Carolina	Water Quality	nil	nil	**+**	**+**
Quebec	Market Welfare	+	**-**	+	+
Pont-Rouge, Quebec	Water Quality	nil	**+**	+	+

Of the four scenarios for the two regions, three cases occur with trade-offs between market welfare and water quality: scenarios 4 and 6 in North Carolina, and scenario 3 in Quebec. Changes involving trade-offs are identified in bold type in Table 24.

In the Southeast, including North Carolina, regional welfare decreases caused by increased costs imposed under scenarios 4 and 6 are compensated to some degree by decreases of nitrates and phosphates in runoff. Decreases in market welfare, after implementing environmental policies, can indicate minimum monetary values attributed to environmental quality, for social welfare to increase or remain unchanged. In scenarios 4 and 6, aggregate benefits derived from environmental quality from 1987-1992 would have to be at least US$169 million and US$377 million, respectively, to prevent a decrease in social welfare. On a per capita basis, minimum benefits are negligible, corresponding to US$0.32 and US$0.71 per year for scenarios 4 and 6, respectively.

In Quebec, a trade-off exists between market welfare and water quality with scenario 3: the welfare change is negative and the change in water quality with respect to nitrogen is positive. Eliminating the ban on US live hog imports in Canada allows imports of hogs from the Midwest into Quebec which accompanies a decrease of hog inventories in Quebec.

Other scenarios elude the trade-off issue because of increases in welfare. In Quebec, both nitrogen and phosphorus plans (scenarios 4 and 6) induce increases in both market welfare (as discussed earlier) and environmental quality.

Free trade, modelled by scenarios 1 and 2, has no direct impacts on water quality in North Carolina or Quebec because inventories change negligibly. Net trade and environmental impacts are positive for the Southeast and Quebec since welfare changes are positive. The net effect to scenario 3, for the Southeast, is also positive.

CHAPTER VII - CONCLUSIONS AND POLICY IMPLICATIONS

Conclusions

Trade liberalization does not appear to contribute to environmental degradation in Raleigh, North Carolina or Pont-Rouge, Quebec given the assumptions used in this study. In fact, leaching of nitrates decreases in Quebec and hence, the contention that international trade is a primary contributor to environmental degradation (Shrybman, 1990) does not hold true for these cases. Environmental conditions could deteriorate in Ontario and Western Canada following the removal of the hog countervailing duty since this trade policy triggers small increases in hog inventories. Since the anticipated effect is minor or nil though, barriers to international trade are not expected to provide a significant protection to environmental endowments.

Even if international trade appears to be a minor or an insignificant contributor to water quality deterioration in the North American hog/pork sector, water quality is mediocre in some of the regions studied. Properly enforced environmental policy taking into account the ecosystem's assimilative capacity is better than trade protection measures to improve water quality.

Both surface and groundwater quality increase when nutrient management plans are implemented. Although this outcome was expected, since nutrient inputs are lowered, the magnitude of impacts, discussed in chapter VII, was measured to evaluate the impacts of environmental policies on water quality (part of the first objective).

Other conclusions stem from the various questions arising from the second objective: assessment of trade patterns and market welfare under various agricultural, environmental and trade policies. The effects of environmental, trade and agricultural policies on trade are summarized first, followed by the effects on welfare.

Environmental policies have a clear impact on trade patterns. The reduction in Quebec inventories triggers a decrease of Canadian live hog exports to the US and an increase of US pork exports to Canada.

Trade and agricultural policy scenarios have a larger impact on trade patterns than on welfare and water quality. When the ban on US live hog exports to Canada is lifted, US live hog exports to Canada increase at the expense of US pork exports and Canadian live hog exports to the US.

The trends and magnitude of impacts from trade policies on welfare are different from impacts induced by environmental policies. Trade policy scenarios trigger increases in North American welfare while environmental policies are responsible for decreases in welfare which could certainly be expected after the cost to spread manure on larger areas increases. The decrease in welfare is the largest when a moratorium in North America is simulated. Since trade liberalization has a positive impact on welfare, the welfare decrease from a moratorium is somewhat attenuated under free trade conditions.

The magnitude of impacts of environmental and trade policy scenarios on regional market welfare also differ markedly. Following trade liberalization, the maximum regional welfare change from the baseline is 1.76%, while under the moratorium on hog inventories, the maximum change is 27%.

Policy implications

New policy recommendations must take into account existing institutions and hence, the legislative structure in Canada and the US is described. Smith and Kuch (1995) provide a comprehensive overview of US legislation. Two federal statutes, the Clean Water Act (CWA) and the Coastal Zone Act Re-authorization Amendments of 1990 (CZARA) impose regulations on livestock operations. Under the CWA, concentrated animal feeding operations (CAFOs) must obtain a National Pollution Discharge Elimination System (NPDES) permit, which focuses on waste storage. Permitted CAFOs must meet the federal standard of no-discharge into US surface waters, except in the case of a twenty-five-year, twenty-four-hour storm. The NPDES program is delegated to forty states, whose agencies implement federal performance standards at their discretion.

The CZARA requires the twenty-nine coastal, and Great Lakes states to develop and implement enforceable "Coastal Nonpoint Control Protection Programs" that meet specific, federal performance standards for livestock operations. CAFOs down to 300 animal units must meet the same, no-discharge standard as required by the CWA for larger operations. Smaller CAFOs, down to 50 animal units, must minimize discharge according to standards at the state level. In addition, many states require that livestock enterprises applying animal waste on cropland have a nutrient management plan following prescribed management practices.

> As with the CWA, decentralization of CZARA implementation is meant to allow for states' accommodation of weather, geography and livestock technology in translating federal standards into state-level programs... Current patterns of interstate regulatory variation and CAFO distribution appear to reflect the political economy much more than they mimic an economically efficient solution to environmental protection... States differ in their interpretations of when or if a NPDES permit is required, in how they translate no-discharge performance standards into requirements for facilities, in the extent to which they exceed federal guidelines, and in how rigorously they enforce implementation... Regulatory rigor does not seem to correlate well with degree of environmental sensitivity to threat from concentrated livestock production (Smith and Kuch, 1995).

Kenyon, Hurt and Zearing (cited in Abdalla *et al.,* 1995) suggest that less stringent water quality regulations in North Carolina were an important factor influencing the movement of hog farms into that state in the early 1990s. However, new legislation is being implemented; for example, nutrient management plans were implemented July 1, 1997 with a maximum mass load for total nitrogen, if the assimilative capacity for nitrogen in a nutrient-sensitive water body is over-allocated. The maximum load shall not exceed the discharge allocation, or 6.0 mg N/L, whichever is less.

Similarly, a Senate Bill proposes, among other articles, the installation of at least one up-gradient and two down-gradient monitoring wells tested semi-annually for contaminants associated with the production of livestock, including nitrogen, copper, zinc, phosphorus, and fecal coliform. A temporary one-year moratorium also became effective January 1 1997.

In Canada, regulation of externalities from agriculture is largely conducted on a provincial basis. Regulations in Quebec are described to indicate one approach to regulation. Information on livestock waste management practices and legislation in different countries or Canadian provinces have been compiled by Runka (1995). In Quebec, regulations enacted in 1981 require certification of any expansion of animal housing or related facilities. A minimum land area ranging from 0.24 to 2 ha, depending on the crop grown, must be available for each animal unit of livestock. One animal unit is defined as five market hogs weighing between 20-100 kg. Manure applications to snow-covered or frozen ground are forbidden unless applied directly to the ground, as are applications within 30 m of a water source. Also, an enterprise must be located at least 150 m (depending on farm size) from residential areas. Expansion of confined operations was prohibited in the Chaudiere, Yamaska and l'Assomption River basins, but moratoriums have been lifted.

Since the requirement for a fertilization plan was recently included in the legislation, the pressure to limit inventories is now linked to assimilative capacity. Results from this thesis show that inventories in Quebec should decrease following the application of nutrient management plans, unless treatment facilities are installed.

To summarize, moratoriums are important policy instruments used in the hog sector. The Government of Quebec has lifted its moratoriums while North Carolina just implemented a one-year moratorium on January 1, 1997. A moratorium is not optimal from an economic perspective because it does not allow supply to respond to market prices and changes in technology. It is not optimal from an environmental perspective because it is not necessarily designed according to assimilative capacity. It is possible that the level of production at the time a moratorium is imposed is either above or below the optimal level determined by environmental conditions and public demand for environmental quality.

Both Quebec and North Carolina have now implemented nutrient management plans based on crop agronomic requirements. Results presented in this thesis, highlight the environmental advantages of enforcing these plans, since surface water quality improves by roughly 80% in Raleigh, North Carolina and by 6% to 39% in Quebec, compared with the baseline.

The overall impact of these plans and any environmental policy depends, of course, on their enforcement. Recently, a group of 18 non-governmental organizations registered a complaint with the Environmental Co-operation Commission of NAFTA alleging that the Government of Quebec neglected to adhere to environmental norms related to agricultural pollution originating from animal, especially hog, production. This is an example of the growing importance of environmental issues in international forums.

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APPENDIX - THE ECONOMIC MODEL

The presentation of the model based on Spinelli's thesis (1991) starts with the identification of the subscript indices. The list of endogenous variables, the predetermined variables and coefficients used in the model are then listed. The equations of the model follow.

Subscripts associated with the variables are:

i,j = production region (j only if you need more than one) (i and j = 1, 2,..., 6),

k = slaughter region (k = 1, 2,..., 8)

l = consumption region (l = 1, 2,..., 8)

f = feed type (f = corn, soybean meal, mineral/vitamin supplement, barley, wheat, protein supplement),

a = age cohort of animal (a = 1, 2, or 3),

t = quarter t

The ordering for subscripts will be: age cohort, region (production then slaughter then consumption), and time period. The subscript T denotes the final time period.

The Endogenous Variables[21]

The following variables (denoted by capital letters) describe the farm production-feeding subsystem:

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[21]Abbreviations used:
dol = dollars; cwt = hundred weight; lwt = liveweight; hce = head capacity equivalent; hd = head; car = carcass; ret = retail; mil = million; and, lb = pound.

N_{ait} = number of pigs and hogs of age cohort a, in production region i, during period t (mil hd);

M_{ait} = marketings for slaughter of hogs of age cohort a, produced in production region i and available for shipment to slaughter regions during period t (mil hd);

TR_{aijt} = number of pigs and hogs of age cohort a, transferred from production region i to production region j, during period t (mil hd);

$BARQL_t$ = quantity of barley used in swine production in Western Canada in period t (mil lbs);

HOGEND = the total number of animals remaining at time period T (mil hd);

SLAUEND = the productive capacity in slaughter and processing facilities remaining at time period T (mil cwt car);

$CAPFARMING_{it}$ = the incremental change in the quantity of farm buildings and equipment which can be used in pig production in period t in production region i (mil hce);

$CAPFARM_{it}$ = physical quantity (e.g., buildings and equipment) available for use in the production of pigs and hogs in production region i, in time period t (mil hce);

$CAPSLAUINC_{kt}$ = the incremental change in the quantity of slaughter and processing capacity in period t in slaughter-processing-storage (SPS) region k (mil cwt car);

$CAPSLAU_{kt}$ = the physical quantity of slaughter and processing capacity available for use in SPS region k in time period t (mil cwt car);

$CULLS_{it}$ = number of culled animals from the breeding stock in production region i during time period t (mil hd);

LWT_{ait} = weight of animals in age cohort a produced in production region i and available for shipment to SPS regions, during time period t (mil cwt lwt); and,

$SLWT_{aikt}$ = weight of animals in age cohort a produced in production region i and actually shipped to SPS region k during time period t (carcass weight basis).

The following variables are determined at the SPS-consumption sub-system level:

P_{kt} = current production (mil cwt car) of wholesale pork cuts (primal cuts) produced in region k during period t;

SO_{klt} = quantity of wholesale pork cuts stored (mil cwt car) in SPS region k at the end of period t (this quantity will be carry-in stocks for period t+1);

Q_{klt} = quantity of wholesale pork cuts (mil cwt car) supplied from slaughter region k to consumption region 1 during period t (this quantity can originate from current slaughter or from stored pork in region k); and,

D_{lt} = quantity of retail port cuts (mil cwt ret) demanded in consumption region 1 during period t.

Coefficients and Pre-Determined Variables

bir = number of pigs born per individual in age cohort 3 per quarter (pigs/hd);

dea_a = death rate of pigs and hogs of age cohort a (%);

awcull = average market weight of a cull from age cohort 3 (cwt/hd);

awbreeder = average market weight of an animal which had been retained in age cohort 3 throughout its life (cwt/hd);

$fprice_{fit}$ = average price of feed by type f in production region i during period t (US$/lb);

$nfcost_{ait}$ = non-feed variable cost associated with the production of pigs and hogs of age cohort a in production region i during period t (US$/hd);

shrhog = losses (shrinkage and deaths) incurred in transit for hogs, traveling from production region i to slaughter region k (%);

$tcpigp_{aij}$ = transportation cost for moving pigs and hogs of age a between production regions i and j (US$/hd);

$tchog_{ik}$ = transportation cost per unit of moving slaughter hogs from production region i to slaughter region k (US$/cwt lwt);

$mcpig_{it}$ = average handling-commission charges to market a hog for slaughter (US$/hd);

$ecap_{ait}$ = expected average daily feed intake for animals of age cohort a in production region i during time period t (lbs/hd/day);

wt_a = average terminal weight of animals of age cohort a (cwt/hd);

tvalhog = terminal value of animals at the end of time period T

(US$/hd);

tvalslau = terminal value of slaughter and processing capacity at the end of time period T (US$/hce);

deprecfarm = depreciation rate on farm buildings and equipment per quarter (%);

survivfarm = survival rate on farm buildings and equipment per quarter (%);

deprecslau = depreciation rate of slaughter and processing capacity per quarter (%);

survivslau = survival rate of slaughter and processing capacity per quarter (%);

cullrate = proportion of new breeding stock which is culled from the breeding herd after one quarter in the age cohort 3 (%);

diehards = proportion of entries into age cohort 3 which survive until the last quarter of the entire assumed life expectancy of a hog (%);

$pdiff_t$ = a constant dollar price penalty on the sale of hogs from age cohort 3 (US$/cwt lwt);

$space_a$ = minimum space requirement for a hog in age cohort a (sq. ft./hce);

r = social welfare discount rate (%);

$\beta_t = (1 + r/4)^{-t}$ = quarterly social welfare discount (%);

capcostf = capital cost involved in establishing new farm buildings and equipment (US$/hce);

recostfarm = recurring costs related to maintaining fixed farm capital, i.e. taxes and insurance (US$/hce);

capcosts = capital cost involved in establishing new slaughter-processing capacity (US$/hce);

recostslau = recurring costs related to maintaining fixed slaughter processing facilities, i.e. taxes and insurance (US$/hce);

$fform_{fai}$ = daily amount of feed requirement f fed to animals of age cohort a in order to meet minimum daily nutritional requirements in production region i, i.e. $fform_{fai}$ equals 69 percent when f = corn and a = 1 for production region i which means that 69 percent of the daily ration for growing pigs must consist of corn (lbs/hd/day);

$ninit_i$ = initial number of pigs and hogs in region i (mil hd);

$adist_a$ = the proportion of the population that must be of age a cohort a to maintain a "steady state" population (%);

dayqu = number of days in a quarter (90 days);

$kill_{ak}$ = slaughter costs for hogs of age cohort a in SPS region k (US$/cwt lwt);

δ_a = dress out percentage for hogs of age cohort a (% of cwt of car per cwt of lwt = car/lwt);

$process_{kt}$ = processing costs in SPS region k (US$/cwt);

cuttoeat = pounds of wholesale cuts needed to make one pound of retail cuts (1.06 cwt of car per cwt of ret = car/ret);

$tcpork_{kl}$ = transportation cost of moving pork from SPS region k to consumption region l (US$/cwt car);

storcost = quarterly storage cost for pork (US$/cwt car);

$imports_{kt}$ = exogenously specified quantity of imports of frozen pork to SPS region k in time period t (mil cwt car);

$exports_{kt}$ = exogenously specified quantity of exports of frozen pork to SPS region k in time period t (mil cwt car);

$military_{kt}$ = exogenously specified quantity of frozen pork used by military sector from SPS region k during time period t (mil car cwt);

$toterritor_{kt}$ = exogenously specified quantity of frozen pork shipped to US territories from SPS region k during time period t (mil cwt car);

$calfac_{t}$ = calibration factor to adjust econometrically estimated demand coefficients with actual demand quantities and prices during the estimation period (real US$/cwt on retail basis);

$inter_{lt}$ = intercept term of demand function for pork in region l in time period t (cwt ret);

$porksl_{lt}$ = partial derivative of quantity of pork demanded with respect to pork price in region l in time period t (US$/cwt ret);

$beefs_{lt}$ = partial derivative of quantity of pork demanded with respect to beef price in region l in time period t (US$/cwt ret);

$chicksl_{lt}$ = partial derivative of quantity of pork demanded with respect to chicken price in region l in time period t (US$/cwt ret);

$perincsl_{lt}$ = partial derivative of quantity of pork demanded with respect to personal income in region l in time period t (US$/cwt ret);

brp_{lt} = retail beef price in region l in time period t (US$/cwt ret);

crp_{lt} = retail chicken price in region l in time period t (US$/cwt ret);

$perinc_{lt}$ = personal income in region l in time period t (thousands of dollars);

pop_{lt} = average population in region l in time period t (mil hd);

cpi_t = the consumer price index of either the US or Canada in time period t (1984-86 = 1);

$rwps_t$ = real wholesale-retail price spread by quarter (real US$/cwt ret);

$chtariff_{ikt}$ = Canadian hog tariff (CND$ per cwt lwt);

$cptariff_{klt}$ = Canadian pork tariff (CND$ per cwt car);

exr_t = Canadian - United States dollar exchange rate (CND$/US$);

Four variables are constructed from parameters to simplify presentation. They are:

$ahatf_{lt} = -(inter_{lt} + calfac_t + beefsl_{lt} * rbrp_{lt} + chicksl_{lt} * rcrp_{lt} + perincsl_{lt} * rperinc_{lt})$;

$porkslf_{lt} = (1/(porksl_{lt} * pop_{lt}))$;

$rnfcosta_{ait} = rnfcost_{it} * space_a$; and,

$rexpenfeed_{ait} = dayqu * fform_{fai} * ecap_{ait} * rfprice_{fit}$.

Equation Specification

The equation set is composed of seventeen constraints and of the objective function. The model also contains several bounds on the initial and final levels for the endogenous variables. The constraints are solved with the Modular Incore Non-linear Optimization System (MINOS) algorithm of GAMS.

There are eleven constraints at the farm level. Birth and invent address the birth and aging of the herd and termdist the population level at the final period. Two constraints are placed on farm production to ensure the replacement of farm buildings and equipment (incfarm and pigcap). One constraint is needed to model the availability of barley in Western Canada (barley). Five constraints are related to herd population dynamics (culleq, cullmart, olddies, livewt and lvtcull). Termqhog determines the terminal value of a hog.

The remaining constraints apply to the SPS and retail demand levels. Incsla and meatcap deal with the slaughterhouse replacement decision; shippedlw and atsps model the physical losses incurred in the processing and marketing of pork from the SPS site to the final consumer use; Dem and sds handle pork demand and utilization; Termqs determines the terminal value of slaughtering facilities.

<u>The Production - Feeding Sub-System</u>

The driving force of the model is the farm production of hogs which is a function of the size and composition of the herd. The latter varies with input and output price changes. Input prices are exogenous while output prices are endogenous, being the marginal value associated with quantity being priced.

i.) <u>Herd Size</u>

Size refers to the absolute number of animals in the herd. The current period's number of animals in the swine population of a region is a function of the pas period's farrowings, deaths, net inter-regional movements of pigs, culls from the age cohort 3 and marketings for slaughter from age cohorts 2 and 3.

i.a) Number of Pigs Born ($birth_{it}$)

The current period's number of pigs in age cohort 1 in production region i is a function of that region's number of breeding stock in the herd and their birth rate from last period plus the net transfer of individuals in cohort 1 in t+1:

$$N_{1,i,t+1} = bir * N_{3,it} - \sum_j TR_{1,ij,t+1} + \sum_j TR_{1,ji,t+1}$$

$$i=1,2,...6;\ t=1,2,...T.$$

1.b.) Maturation of the Population ($invent_{ait}$)

Animals present at the beginning of period t must either 1) remain in the herd and age one period, 2) be marketed for slaughter as a market hog 3) be marketed inter-regionallly for breeding or feeding purposes, or 4) die a natural death. No hog is allowed to live more than 12 quarters.

$$N_{a+1,i,t+1} = (1-dea_a)*N_{ait} - M_{ait} - \sum_j TR_{aijt} + \sum_j TR_{ajit}$$

$$\text{if } a = 1;\ i = 1,2,\ldots 6;\ t = 1,2,\ldots T.$$

$$N_{3,i,t+1} = (1-dea_3) * N_{3,it} - M_{3,it} - \sum_j TR_{3,ijt} + \sum_j TR_{3,jit} + (1-dea_2) * N_{2,it} - M_{2,it} - \sum_j TR_{2,ijt} + \sum_j TR_{2,jit}$$

when $a = 2,3$; $i = 1,2,\ldots 6$; $t = 1,2,\ldots T$.

ii.) <u>Composition of the Herd</u>

The composition of the herd is the distribution of the herd across the three age cohorts. Any contraction or expansion of the herd depends on the size of cohort 3, the breeding herd. The retained breeding herd numbers are the residual from marketings and death losses.

ii.a) Number of Culls Marketed ($culleq_{i,t+1}$)

The number of animals culled from age cohort 3 are a fixed proportion of the number of animals entering the cohort in the previous quarter:

$$CULLS_{i,t+1} = (N_{2,it} - M_{2,it} - \sum_j TR_{2,ijt} + \sum_j TR_{2,jit}) * (1-dea_2) * (cullrate).$$

ii.b) Minimum Number Marketed from Age Cohort 3 ($cullmart_{it}$)

The following constraint ensures that at least the culls (defined in ii.a) are marketed from age cohort 3 each quarter:

$$CULLS_{it} \le M_{3,it}$$

ii.c) Forced Marketings of Three Year Old Hogs ($olddies_{i,t+9}$)

Hogs of cohort 3 must be marketed after nine quarters:

$$(N_{2,it} - M_{2,it}) * (diehards) * (1-dea_3)^{10} \le M_{3,i,t+9}$$

ii.d) Liveweight of Culls in Marketings ($lvtcull_{it}$)

Culls from cohort 3 will be lighter than mature breeding animals from this age cohort:

$$LWT_{3,it} \le awcull * CULLS_{it} + awbreeder * (M_{3,it} - CULLS_{3,it})$$

ii.e) Liveweight of Others Marketed ($livewt_{ait}$)

This constraint accounts for total carcass weight of the marketed animals in age cohorts 1 and 2:

$$LWT_{ait} \le wt_a * M_{ait}$$

iii) Capital Formation

Dynamics in hog production does not only involve the physical production linkages between quarters and the portfolio choice of producers of marketing current stock or retaining it to produce future revenues as shown in the previous equations, but also the replacement of durable production assets at the farm and SPS levels. The capital cost enters each level as a fixed outlay in the quarter the assets are acquired and as a recurring expenditure based upon the costs of insurance and taxes.

iii.a) Farm Capital in Place ($pig\ cap_{it}$)

Farm production facilities are a function of the hog inventory:

$$\sum_a space_a * N_{ait} \le CAPFARM_{it}$$

iii.b) Farm Capital Dynamics ($incfarm_{it}$)

The actual farm capital is a function of depreciation and incremental changes in capital:

$$CAPFARM_{it} - survivfarm * CAPFARM_{i,t-1} \leq CAPFARMINC_{it}$$

iii.c) SPS Capital In Place ($meatcap_{kt}$)

$$1.5^{22} * P_{kt} \leq CAPSLAU_{kt}$$

iii.d) SPS Capital Dynamics ($incslau_{kt}$)

$$CAPSLAU_{kt} - survivslau * CAPSLAU_{k,t-1} \leq CAPSLAUINC_{kt}$$

iv.) <u>Initial, "Steady State", and Terminal Conditions for Stock Variables in Farm Production</u>

The initial hog inventory, which is fixed, increases or decreases according to economic incentives given the biological constraints. These constraints (e.g. number of piglets weaned per sow) affect the distribution of the hog inventory between the 3 cohorts.

iv.a) Initial Population Distribution

The initial regional hog inventory is entered as a fixed bound on each cohort.

iv.b) Terminal "Steady State" Population Distribution ($tremdist_{ai,T}$)

$$\sum_{bb} ((-dist_a * N_{bb,i,T}) \text{ if } a \neq bb + (1-dist_a) * N_{bb,i,T} \text{ if } a = bb) = 0$$

iv.c) Terminal Condition on Number of Hogs (termqhog)

Terminal quantities must be imposed at both the farm and SPS levels otherwise the maximization problem will trigger the marketing of all hogs to be consumed as pork without taking into

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[22] Multiplication by 1.5 allows for any intra-seasonal variation in processing.

account the value that future generations place of hog production capacity.

$$HOGEND \leq \sum_a \sum_i N_{ai,T}$$

iv.d) Terminal Condition on SPS Slaughter Capacity (termslau):

$$SLAUEND \leq \sum_k CAPSLAU_{k,T}$$

v.) <u>Barley Supply</u> ($barley_{it}$):

A step supply function is constructed to reflect the fact that availabilities rather than prices have an effect on livestock production:

$$\sum_a qfeeduse_{barley,a,West\ Canada,t} * N_{a,West\ Canada,t}$$
$$\leq BARQL_t + BARQM1_t + BARQM2_t + BARQM3_t$$
$$+ BARQM4_t + BARQH_t$$

<u>The SPS - Consumption Sub-System Level</u>

Pork production on a carcass weight basis is the sum of the total live weight marketings adjusted for transport and dress-out losses shipped from production regions to each SPS site.

vi. a) Live Hog Shipments to SPS Sites ($shippedlw_{ait}$)

$$\sum_k SLWT_{aikt} \leq LWT_{ait}*(1\text{-}shrhog)$$

vi.b) Wholesale Primal Cut Production at SPS Site ($atsps_{kt}$)

$$P_{kt} \leq \sum_i \sum_a \delta_a * SLWT_{aikt}$$

P_{kt} is expressed in total weight on a carcass weight basis available for storage or shipment to demand regions.

vi.c) Pork Utilization Row (sds_{kt}):

The following equation is an accounting equation of pork flows and use across time period. The quantity of pork held in storage in period t+1 in slaughter region k is the amount of pork remaining from the activities in period t: storage carried into period t, pork production during period t, imports, exports, military use and quantities sent to demand regions:

$$SO_{k,t+1} + \sum_{l} Q_{kl,t+1} - P_{k,t+1} - imports_{k,t+1}$$
$$+ exports_{k,t+1} + military_{k,t+1}$$
$$+ toterritor_{k,t+1} \leq SO_{kt}$$

vi.d) Pork Demand (dem_{lt})

Total demand can not exceed the total weight of carcass shipped in from slaughter regions adjusted for "cut to eat" trimming losses at the retail marketing level:

$$D_{lt} \leq \sum_{k} \frac{Q_{kit}}{cuttoeat}$$

vii.) <u>The Objective Function</u>

The model's objective function is to maximize the area under each region's pork demand function in each quarter minus all costs in production, marketing, slaughter, processing, and distribution. Hence there is a revenue component and a cost component.

vii.a) The Revenue Component

Revenue from the sale of the final composite pork product takes the following form:

$$\sum_{t} \beta_t * \sum_{l} (ahatf_t*D_{lt} + 0.5*porkslf_{lt}*D^2_{lt})$$

vii.b.) The Cost Component:

Costs at each level (farm, SPS, and consumption) are presented.

vii.b.1) Feed Costs

Feed requirements are multiplied by feed prices. For each animal of age cohort a, an average daily feed intake ($ecap_{ait}$) to provide the nutritional requirements is specified for each region. Potential feeds include corn, soybean meal, mineral/vitamin supplement, barley, wheat, and protein supplement. Each region's specified feed set is contained in the parameter $fform_{fai}$. Quarterly feed costs consist of this average daily ration multiplied by the number of days in a quarter (dayqu) times the price of each feed type ($rfprice_{fit}$) times the number of livestock in each age cohort:

$$-\sum_{t} * \beta_t * \sum_{a} \sum_{i} \sum_{f} dayqu * rfprice_{fit}$$

$$* fform_{fai} * ecap_{ait} * N_{ait} \text{ ; or,}$$

$$-\sum_{t} \beta_t * \sum_{a} \sum_{i} rexpenfeed_{ait} * N_{ait}$$

vii.b.2) Non-Feed Variable Costs

Non-feed variable costs are veterinarian expenses, fuel, electricity, and breeding costs on a per head basis:

$$-\sum_{t} \beta_t * \sum_{a}\sum_{i} rnfcost_{ait} * N_{ait}$$

vii.b.3) Fixed Costs

Farm capital costs enter into the model as large initial cost outlay at the time of acquisition and recurring quarterly expense outlays until the facility is completely depreciated:

$$-\sum_{t} \beta_t * \sum_{i} rcapcostf_t * CAPFARMINC_{it}$$

$$-\sum_{t} \beta_t * \sum_{i} rrecostf_t * CAPFARM_{it}$$

vii.b.4) Hog Marketing Costs

Handling and commission charges are levied on each hog when they are marketed:

$$-\sum_{t} \beta_t * \sum_{a}\sum_{i} rmcpig_{it} * M_{ait}$$

vii.b.5) Feeder Pig Transfer Costs

Pigs which are raised on one farm to feeder pig size and then shipped across production regions to another farm incur transportation charges:

$$-\sum_{t} \beta_t * \sum_{a}\sum_{i}\sum_{j\neq 1} rtcpigp_{ijt} * TR_{aijt}$$

vii.b.6) Transportation Cost to Slaughter Plant

Transport costs of market hogs to slaughter plants are charged on a live weight basis:

$$-\sum_{t} \beta_t * \sum_{a}\sum_{i}\sum_{k} rtchog_{ikt} * \left(\frac{1}{1 - shrhog}\right) * SLWT_{aikt}$$

vii.b.7) Slaughter Cost

Costs related to the slaughter of hogs are as follows:

$$-\sum_{t} \beta_t * \sum_{a} \sum_{i} \sum_{k} * \; rkill_{akt} * SLWT_{aikt}$$

vii.b.8) Processing and Storage Costs

All production must be cut into primal cuts for fresh meat, and processed in the case of prepared meats. Once processed, wholesale meat may go directly to retail sites or tstorage for later shipment. Processing and storage costs are:

$$-\sum_{t} \beta_t * \sum_{k} (rprocess_{kt} * P_{kt} + rstorcost_t * SO_{kt})$$

vii.b.9) Fixed Costs on SPS Capacity

As with farm capital costs, SPS capacity costs enter into the model as a large initial cost outlay and recurring quarterly expense outlays:

$$-\sum_{t} \beta_t * \sum_{k} recapcosts_t * CAPSLAUINC_{kt}$$

$$-\sum_{t} \beta_t * \sum_{k} rrecosts_t * CAPSLAU_{kt}$$

vii.b.10) Pork Transportation Costs

Transportation costs of wholesale meat leaving the SPS site for the retail demand centers enter the objective as:

$$-\sum_{t} \beta_t * \sum_{k} \sum_{l} rtcpork_{klt} * Q_{klt}$$

vii.b.11) Price Discounts on Fat Hogs

Fat hogs are marketed at a discounted price compared to market hogs. The price penalty is modelled as follows:

$$-\sum_{t} \beta_t * \sum_{i} \sum_{k} pdiff_t * \left(\frac{1}{1 - shrhog}\right) * SLWT_{3,ikt}$$

vii.b.12) Marketing Margins

The wholesale-retail price spread is seasonal and enters in this way:

$$- \sum_{t} \beta_t * \sum_{l} rwps_t * D_{lt}$$

vii.b.13) Terminal Values

The salvage values for the terminal period herd and terminal period slaughter facilities are added to the revenue component:

$$+ (TVALHOG*HOGEND) + (TVALSLAU*SLAUEND)$$

vii.b.14) US Countervailing Duties

Tariffs on Canadian hogs and pork exported to the US are modelled as costs:

$$- \sum_{t} \beta_t * \sum_{a} \sum_{i} \sum_{k} rchtariff_{ikt} * SLWT_{aikt}$$

if i = Atlantic provinces, Quebec, Ontario or Western Canada production region

and k = US SPS site:

$$-\sum_{t} \beta_t * \sum_{k} \sum_{i} rcptariff_{kit} * Q_{klt}$$

if k = Canadian SPS site

and l = US demand site

vii.b.15) West Canadian Barley Supply

A step supply function for Western Canadian barley is created by setting bounds on separate quantities of barley in Western Canada, each subsequent quantity having a higher price (real US$/lb):

$$-\sum_t \beta_t * (0.02*BARQL_t + 0.03*BARQM1_t + 0.04*BARQM2_t + 0.08*BARQM3_t + 0.09*BARQM4_t + 0.1*BARQH_t)$$

vii.b.16) Risk from Hog Price Variability

The standard deviation of endogenous hog prices is used as a proxy for risk:

$$-\sum_t \beta_t * 0.3\ RISK_t$$

vii.b.17) Stabilization Payments:

Expected stabilization payments are government subsidies provided 3 quarters before the hogs are marketed:

$$-\sum_t \beta_t * 0.12\ RSTAB_t$$