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Analyzing the Impacts of the Proposed North American Free Trade Agreement on European-North American Dairy Trade Using a Joint-Input, Multi-Product Approach

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ABSTRACT

Mathematical programming models, as typically formulated for international trade applications, may contain certain implied restrictions limiting price responsiveness, intermediate product flows, and arbitrage possibilities. These restrictions are especially important in the case of dairy, and may lead to results which are technically infeasible, or if feasible, not consistent with market equilibrating behavior. The difficulties encountered when modeling dairy trade are described, and an alternative formulation of a spatial model is presented. This formulation allows joint-inputs, multi-products, intermediate markets, and pure transshipment and product substitution forms of arbitrage.

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INTRODUCTION

On January 1 1994, the proposed North American Free Trade Agreement (NAFTA) is expected to take effect. As a result, Mexico's current pattern of dairy trade may be altered. The preferential access to the Mexican dairy market, which the NAFTA would afford the U.S., may allow the U.S. to increase its market share primarily at the expense of the European Economic Community (EEC), currently the largest exporter of dairy products to Mexico. On the other hand, increased Mexican access to the U.S. dairy market presents Mexico with significant opportunities for arbitrage. Analyzing the impacts of the proposed NAFTA raises a number of modeling issues which are common to many trade analyses, especially dairy trade. It is the purpose of this paper to outline these issues and present an alternative formulation of a spatial trade model which addresses these concerns. The paper begins with some general comments about trade models, agricultural protection, and a brief discussion of the NAFTA as it relates to dairy.

Over the last decade or so, numerous models have been constructed and used to estimate both the cost of agricultural protection and the impact of reforming trade distorting agricultural policies. A glance at the trade liberalization literature reveals that mathematical programming models, of one form or another, are frequently chosen as the most appropriate tool to perform such analyses. This paper will argue, however, that the typical construction of mathematical agricultural trade models may contain several serious shortcomings. Particularly in the case of dairy, spatial trade models can invariably be shown to produce results which are actually infeasible, or if feasible, are not good representations of reality. Statistical models, while never intended to derive truly representative solutions, may suffer problems with infeasibility too because their typical construction also fails to require mass balancing constraints.

The production and consumption of milk and its derivative products occurs in almost every country. Surprisingly, only about 6 percent of total world milk production enters world markets in the form of processed milk products. The bulky and perishable nature of fluid milk provides a partial explanation for this phenomenon. The high level of government intervention in dairy markets, especially in developed countries, provides further explanation. Indeed, the governments of most countries intervene in almost all their agricultural markets so that production and price levels are determined in accordance with national social objectives. Such objectives are many and varied. Anderson and Tyers (1990), Honma and Hayami (1986), and Gardner (1987) provide explanations for the persistence of agricultural protection, and why it has increased so dramatically since the 1950's. State support for the agricultural sector seems especially pervasive in developed countries while in less developed nations the reverse is generally true; agriculture tends to be taxed. The consequences of intervention include the distortion of international agricultural trade flows, reduced national and global welfare, and input and output prices which result in levels and patterns of agricultural production that foster an inefficient use of the intervening country's resources.

It is well understood that the process of untangling the complex pattern of distortions and interventions is problematic. That it needs to be untangled is rarely disputed. Among all agricultural sectors, resolving these problems for the dairy sector is perhaps the most difficult because it seems to have become one of the most protected. Blayney and Fallert (1990) tabulate the estimated world price effects under trade liberalization for 5 agricultural commodities according to 7 major studies. In all but one, the estimated price increases are the greatest for dairy.

THE NORTH AMERICAN FREE TRADE AGREEMENT

U.S. President George Bush and Mexican President Carlos de Gortari agreed in June 1990 to initiate negotiations aimed at reaching a bilateral agreement to reduce and/or eliminate tariff and non-tariff barriers to trade. The stated purpose for doing so was to strengthen economic relations between the two countries and to improve international competitiveness. Canada was invited to join the negotiations in December 1990. However, Canada's dairy sector would be excluded from the NAFTA because the 1989 U.S.-Canada Free Trade Agreement (FTA) already regulates agricultural trade between these two countries and it excludes dairy. The draft text of the proposed accord was officially signed by the leaders of the three countries on October 7, 1992. Since that time, of course, the Presidency of the U.S. has changed and some additional side-agreements addressing the new Administration's concerns about worker rights and environmental safeguards are being negotiated. If negotiations follow the Administration's timetable, and the resulting agreement is ratified by the respective governments, then the NAFTA will take effect on January 1 1994.

The provisions which would directly affect the dairy sector relate to market access, rules of origin, and sanitary standards. Under the market access provisions, all non-tariff barriers (import licenses) to Mexican dairy imports from the U.S. would be immediately converted to ad valorem tariffs, with the exception of nonfat dry milk (NDM). For most products, the tariff rate would initially be 20 percent and would be subject to a straightline phase-out over 10 years. In the case of NDM, the U.S. would initially be granted a 40,000 metric ton (MT) tariff-rate quota (TRQ) which would increase at an annual compounding rate of 3 percent. The over-quota tariff would start out at 139 percent and reduce to zero over 15 years. In otherwords, all dairy products except NDM could be imported to Mexico from the U.S. completely free of barriers after 10 years, and after 15 years for NDM.

The market access provisions for the U.S. are slightly different because of the need to accommodate the existing "Section 22" dairy import quotas. Non-NAFTA countries would continue to be subject to the Section 22 quotas, but Mexico would be granted preferential access to the U.S. dairy market by way of tariff-rate quotas. The TRQ's would be set initially at 5 percent of the total current Section 22 quota levels, and would increase at an annual compounding rate of 3 percent. Over-quota tariffs would range from 76 to 90 percent and would reduce to zero over 10 years. In otherwords, after 10 years dairy exports from Mexico to the U.S. could occur free of any economic restrictions. With the exception of cheese, the initial quotas to be granted to Mexico would be quite small and are as follows: 5,550 MT of any cheese product; 366 MT of fluid milk, cream, or ice-cream; 422 MT of dried milk products; 43 MT of butterfat products; and 733 MT of condensed milk products.

The proposed NAFTA stipulates strict rules of origin because of the concern by U.S. producers that non-NAFTA countries might circumvent the U.S. Section 22 import quotas by shipping products to the U.S. via Mexico. Essentially, any dairy product entering the U.S. duty-free under NAFTA must originate in a NAFTA country. Given that Canada is excluded from the NAFTA's dairy provisions, the rules are specified such that all Section 22 dairy products, and the components of those products, must originate in Mexico. Almost all dairy products are explicitly excluded from the so-called *de minimus* rule (Article 405, U.S.I.T.C., 1992) which provides that up to 7 percent of the value of any product can be composed of non-NAFTA originating components. Thus, cheese produced in Mexico would not be considered of Mexican origin if it contains milkfat or nonfat solids imported from the EEC. Similarly, condensed milk reconstituted in Mexico from New Zealand butteroil and NDM would also not be considered of Mexican origin (Vitaliano, 1992).

The NAFTA, as currently proposed, imposes a number of protocols on the development, adoption, and enforcement of sanitary and phytosanitary measures. These are designed to prevent trade restrictions from being disguised as sanitary and phytosanitary measures. In addition, the harmonization and equivalence of sanitary standards is to be encouraged. Each participating country is permitted, however, to adopt more stringent sanitary and phytosanitary standards provided they are based on scientific evidence and are not applied in an arbitrary or discriminatory manner.

Mexico is consistently milk deficient because its steady increase in consumption outpaces the rate of growth in milk production. NDM and butter and butteroil are the major dairy products imported by Mexico. Reconstituted fluid milk is the dominant use of such imports. Since 1983, Mexican imports of NDM have averaged 193,379 metric tons per year which represents almost one half of the worlds total imports of NDM. The EEC has supplied approximately 40 percent of these imports while the U.S. share has been around 35 percent. New Zealand and Canada have averaged 15 and 10 percent shares respectively. The EEC also provides significant quantities of butter and cheese to Mexico. Economists tend to agree that the program of general economic reforms in Mexico will eventually lead to notable income and dairy consumption increases. Hence, Mexico promises to remain a significant net importer of dairy products in the future.

Many U.S. dairy processors view the proposed NAFTA as a means of increasing exports to Mexico, mostly at the expense of the EEC. However, this view reflects only one part of the overall picture because the NAFTA also provides Mexico with preferential access to the U.S. market. The stipulations governing the rules of origin in the proposed NAFTA agreement clearly seek to prohibit product sourced in non-NAFTA countries from being transshipped to the U.S., or from being reprocessed in Mexico into products destined for the U.S. It is not clear, however, that such a restriction can be practically enforced. Several arbitraging mechanisms exist for Mexico to exploit its preferential status with the U.S. For example, Mexico might import from the EEC, taking advantage of EEC export subsidies, and then forward the products to the U.S. at a higher but still competitive price. This type of activity would clearly violate the NAFTA's intent and seems relatively easy to prevent. Secondly, products from the EEC might be reprocessed, with or without Mexican milk, into product forms which are then shipped to the U.S. Such activity would also be counter to the NAFTA's intent but is entirely possible and seems more difficult to guard against. Finally, exports from the EEC could be consumed in Mexico thereby facilitating the manufacture of exportable products from Mexican milk when such milk otherwise wouldn't have been available for export purposes. This could occur even with factor price equalization. It could be argued that this type of activity, while not violating the language of the NAFTA, would also be a violation of its intent. Amending the proposed rules so as to prevent this would be very difficult. This latter form of arbitrage might be termed consumption substituting arbitrage.

DESIGN ISSUES ASSOCIATED WITH MODELING DAIRY TRADE

Several important issues need to be considered when modeling dairy trade. The challenges facing those who seek to model dairy trade are not necessarily unique to dairy although, in this paper, they are discussed only in the context of dairy. The problems described here are very much interrelated and include the following: the choice of consistent units of measurement for both milk and processed dairy products, the level of product aggregation, the procedure by which the conceptual model is made operational, the degree of policy specificity, the number of market levels to include, and inclusion of the potential for arbitrage.

1. Units of Measurement for Milk and Milk Products:

Most dairy models include a farm milk supply sector and some representation of the markets for the products derived from milk. Hence it is necessary to express raw milk and the various demanded milk products in equivalent units. The problems associated with this seemingly simple task arise from the joint-input, multiple-output structure of the dairy sector. Milk consists of several components (inputs for demanded dairy products), and demanded dairy products use these components in different proportions. For instance, butter is highly fat intensive and contains few other milk solids. NDM, on the other hand, contains practically no fat but is comprised primarily of proteins and carbohydrates. Cheese contains both fat and protein but only small amounts of carbohydrates, principally lactose. Even fluid milk products are comprised of components in different proportions than their raw milk input. Raw milk supplies too, show substantial variation with respect to composition across regions. For example, the average fat content of raw milk in New Zealand is over 4.7 percent while in the U.S. it is less than 3.7 percent.

In the past, computational complexities often necessitated the use of homogeneous measurements in multi-product models, such as the use of milkfat based milk equivalents in dairy models, for example, Lattimore et al. (1987) and OECD (1991a). Although this makes the problem more tractable, it imposes unrealistic restrictions on the process of allocating milk to the various products produced from milk. A simple example illustrates how this is so. Consider a model which has a milk supply sector and demand markets for four products; butter, NDM, cheese, and fluid milk. Assume that the supply of raw milk is held constant,** and that milk as well as all four products are expressed in milkfat equivalent units. Suppose the demand for NDM increases due to some exogenous factor. In order to satisfy the increased demand for NDM, and because the supply of raw milk cannot change, the model must now reallocate milk

**This assumption is made only for ease of exposition. Relaxing it does not change the general outcome.

away from one of the other three products. The fat equivalent of NDM is very small; thus the model would grossly understate the amount of milk actually reallocated. The reverse would be true, albeit to a lesser extent, if the increased demand were of butter. Furthermore, and more importantly, many dairy products are actually jointly produced. An increase in the production of butter results in the availability of more nonfat milk solids; an increase in the production of fluid milk products most often results in surplus cream. These complex interactions are difficult, if not impossible, to represent in a single product and/or single component formulation.

In addition to the allocation problem, the single component formulation also presents difficulties when models are required to assign values to milk and milk products, and to the components of milk. The fat component of milk has few final product uses and tends to be less valued relative to the nonfat components. It is from the nonfat components that most new dairy products are developed. Unwanted milkfat is more often than not made into butter and then exported at a price sufficiently low enough that its disposal is assured. A model using a single milk equivalent measurement presupposes that a price increase for one product necessarily implies a price increase (or at least not a price decrease) for all other products included in the model. Of course, in actuality there is no reason why this should be the case. In the example above, an increase in the price of NDM may well be associated with a decrease in the price of butter.

2. Product Aggregation:

From a practical standpoint, product aggregation leads to a number of modeling efficiencies, especially in a multi-sector model. Aggregation can alleviate the difficulties related to homogeneous units of measurement in multi-product models. The more it does so, however, the more it exacerbates problems caused by the fact that the demands for different products may well imply quite different demands for components and this would likely result in product prices moving in opposite directions. The logical solution to the aggregation problem is to model the dairy sector as a multi-product sector. Of course, there are disadvantages with this solution, principally the data required. Few dairy trade models, it seems, provide a satisfactory resolution to this problem. Even when milk products are aggregated, their aggregate composition varies markedly between countries and even between areas within a country. An example of a model in which the demand side of the dairy sector is aggregated into just two products, fluid milk and manufacturing milk, is the widely referenced Ministerial Trade Mandate (MTM) model (OECD, 1991b).

There are two primary reasons for enumerating the products as completely as possible. Most importantly, a model which includes a range of products that fully accounts for all uses of milk, while reflecting the range of possible component uses, enables the milk supply sector to be properly represented. This seems obvious given the need to balance milk supply with product demand, yet surprisingly, some models fail to provide a mass balancing linkage for components between the milk supply sector and product demands. Baker (1991), for example, proposes a spatial equilibrium model to analyze the impacts of the U.S.-Canada FTA on the dairy sector. While the theoretical presentation of the model includes an input-output transformation constraint (page 65, equation 2(c)), it is switched off for the actual analysis (page 81-82). Statistical models typically ignore the problem completely (Lattimore, 1987, and FAPRI, 1992). It is unlikely that truly meaningful or even technically feasible results can be attained when such mass balancing constraints are not considered, and when the model is used to analyze the impacts of structural change.

Secondly, when major policy instruments affect a particular product, it is prudent to separate that product in the model from other products not so affected. This applies to domestic policies, such as government product purchases used to enforce a minimum price, to border policies, such as product specific import quotas, and to policies affecting the fluid milk sector, a sector which is not even included in many dairy trade models. Fluid milk markets are inextricably linked to manufactured product markets through milk component balancing. In developed countries, where per capita milkfat consumption is steadily declining, the fluid milk market usually supplies significant quantities of excess fat solids to the manufacturing milk sector. The multi-product, multi-component formulation alluded to above provides a mechanism for the interaction of the fluid and manufacturing sectors to be captured. Furthermore, policies influencing one product tend to have carryover effects on other products and/or on the supply of milk because all products compete for the same pool of milk components which are available only in a fixed proportion. Aggregation of these products into one category masks the response taking place in each individual market.

3. Making the Conceptual Model Operational:

Here the purpose is not to review and compare all methodological approaches, but rather to point out the restrictions imposed by the ones commonly used. Designing and constructing a model, such that it may usefully represent the operation of international markets, presents the model builder with a complex set of choices. Ultimately, these choices are made based upon the research objectives, the current state of the art of modeling, and the individual's own methodological preferences and biases.

First, the method by which net trade positions are determined turns out to be particularly crucial. A spatial model, one capable of reproducing trade flows between each pair of traders, is required if discriminatory trade policies are to be analyzed (Anania and McCalla, 1991). Models based on an a priori definition of the sets of importing and exporting regions, such as those where the countries are represented through their excess supply or demand schedules, simply assume away the possibility of switching from one side of the market to the other. Also, models based on internal supply and demand responses, rather than excess schedules, more easily allow the explicit incorporation of policy instruments.

Secondly, the theory of spatial price relationships offers some guidance as to how a model ought to establish prices. That is, assuming competitive markets, the difference in prices between regions must be less than or equal to the transfer cost between those regions (Tomek and Robinson, 1990). More specifically, it will be equal in the case of regions that trade and less than the transfer cost in the case of regions which don't. Thus, a theoretical basis for directly linking prices between regions exists only for those regions that actually trade with each other. A number of models seem to overlook this implied bound on regional price differences by using explicit price linkage equations to link the price in all regions with a so-called world, or reference, price. For instance, the SWOPSIM model (Roningen et al., 1991) computes domestic prices in each region as a function of the world price and a price wedge representing policy interventions. Price determination mechanisms of this type are commonplace, largely because they are relatively simple to model.

Models which use "reference" prices typically use the New Zealand border price as the reference in the case of dairy because New Zealand is a major dairy exporter, and because New Zealand's dairy sector is relatively undistorted by government interventions (Tyers and Anderson, 1986). However, in a liberalized trading environment, it is not at all clear that such a reference would continue to make sense. The supply of farm milk in New Zealand is very inelastic due to the constraint of land availability. In a substantially altered trading environment, New Zealand may or may not be a dominant participant in the market.

Trade theory also predicts that in the absence of barriers to trade, factor prices will equalize across trading partners. When considering dairy products trade, the components of milk, fat and nonfat solids for example, may be viewed as factors. It is, after all, the components of milk which are demanded and traded in the form of manufactured products. This is especially true in the case of trade in intermediate products such as milk powder, bulk-packaged butter and cheese, and casein. Thus, a dairy trade model must incorporate some mechanism for assigning a value to the components of milk.

The use of linear supply and demand functions is particularly restrictive when the objective of the research is to understand how changes to existing policy structures will affect agents' behavior. Such is the objective in the trade liberalization research. Just et al. (1977) demonstrated the pitfalls of relying on linear functions when the problem to be analyzed contains significant nonlinearities. The availability of nonlinear solvers makes the use of linear functions where they are not the most appropriate functional form ill-advised.

4. Policy Specificity:

A fourth issue to arise when building dairy trade models concerns the degree of policy specificity. A wide array of policy instruments exist in dairy sectors. These include the following: support prices, restrictions on imports, export subsidies, production quotas, payment based quotas, levies and assessments, deficiency payments, and classified pricing programs. Frequently, for modeling purposes, these policies are aggregated into some kind of price wedge representation. Alternatively, models that derive solutions using net trade functions attempt to capture policy effects in the elasticities of those functions. The difficulty with either of these approaches is that the way in which individual policy instruments affect domestic and international markets is grossly simplified. Consequently, the information available to decision-makers, who must formulate responses to particular policies, is frequently not very specific.

Support policies often target a specific product and are designed to have secondary, but no less important, effects on other products. The classified pricing and pooling and the support price systems in the U.S. are cases in point. For example, changes in the more administratively determined Class I (fluid) prices paid by processors may have substantial impacts on the more market oriented prices paid by the processors of manufactured products. Similarly, Class III products meeting certain specifications are purchased by the government at what amounts to a floor price. However, this action also provides, and is intended to provide, a minimal, although less well defined, price for non-Class III products. Clearly, such interactions are more precisely understood the more explicitly policies are modeled.

5. Market Levels (Processing Sector):

The appropriate market levels to include is yet another issue the model builder must resolve. Typically, trade models include a set of supply regions and a set of demand regions while making no reference to any intermediaries. Such a framework falls short of the mark in the case of dairy where numerous product transformations are possible and common, and intermediate products are frequently traded. The New Zealand Dairy Board, for example, exports over 400 different product specifications. Theoretical representations of derived supply or demand are misleading given the complexities of a multi-product world. Excluding the processing sector from a dairy trade model, therefore, seems difficult to justify, especially if the farm milk supply sector is to be included.

The processing sector performs the tasks of allocating milk to the various products, balancing components, and providing the wholesaling role. In addition, its inclusion allows for the analysis of a segment of the industry which is often ignored, but is responsible for much of the decision making. It is processing companies or their agents who are largely responsible for the international marketing of dairy products. Furthermore, policies intended to support dairy farming are often implemented at the processing level. If policies are to be modeled explicitly, as suggested above, then inclusion of a processing sector becomes necessary.

6. Potential for Arbitrage:

Inclusion of the processing sector also allows a model to explicitly accommodate the possibility for arbitrage, the final issue to be addressed in this section. This issue seems to be ignored in much of the trade liberalization literature, although the potential for arbitrage arises with any trade agreement that confers a preferential status on a select set of trading partners. The issues surrounding rules of origin and arbitrage possibilities cannot be analyzed unless the model is specified appropriately. Anania and McCalla (1991) have already pointed-out, in a single product framework, how typical spatial models implicitly set restrictions on this activity. Non-spatial models simply ignore the issue completely. A model which is to be used to analyze the NAFTA, or any other preferential trade agreement, must be specified such that arbitraging is possible.

THE MODEL

In this section, a joint-input, multi-product spatial trade model is described. The model addresses those issues discussed earlier. Conceptually, the model derives an equilibrium in which component quantities are balanced, and purchase and selling prices equate after taking transportation costs, processing costs, tariffs, and export subsidies (generalized delivery or transshipment costs) into account. To find the equilibrium, the model maximizes the net difference of the integral under the inverse milk supply and product demand functions. While Samuelson (1952) called this the *net social payoff,* it need not be assigned any welfare connotations. It is simply an algorithm intended to find a multi-market equilibrium.

The model contains several features that distinguish it from the existing models used to analyze dairy markets. Most importantly, raw milk is allocated to the various processed products on a milk component basis. The number of components able to be included in the model is limited only by the modeler, as is the number of products. Secondly, the model is based on internal price responsive supply and demand functions. A number of advantages follow from such a construction; a region can switch from one side of the market to the other as prices for the various products change; the various types of arbitraging discussed earlier are allowed; and specific policy instruments are more easily incorporated and their effects analyzed. Thirdly, the structure allows for a mixture of functional forms. For instance, price support programs which utilize government purchases at some minimum fixed price can be represented with a perfectly elastic demand function whereas it may be preferred that commercial demand be nonlinear. Finally, the model includes a processing sector, improving both its flexibility and its realism.

Following Takayama and Judge (1971), the model may be stated as follows:

$$\max \ NW = \sum_{j=1}^{J}\sum_{k=1}^{K}\theta_{jk}(y_{jk}) - \sum_{i=1}^{I}\phi_i(s_i)$$

$$-\sum_{\ell=1}^{L}\sum_{j=1}^{J}\sum_{k=1}^{K}[(t_{\ell jk} + w_\ell + \pi_{\ell jk} - \sigma_{\ell jk})x_{\ell jk}] \tag{1}$$

$$-\sum_{\ell=1}^{L}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{k=1}^{K}[(t_{\ell mk} + w_\ell + \pi_{\ell mk} - \sigma_{\ell mk})xx_{\ell mjk}]$$

$$-\sum_{\ell=1}^{L}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{k=1}^{K}[(t_{mjk} + \pi_{mjk} - \sigma_{mjk})xx_{\ell mjk}]$$

subject to:

$$s_i - \sum_{\ell=1}^{L} xs_\ell \geq 0, \quad \forall \ i=1, \ldots, I \tag{2}$$

$$\psi_{\ell n} * xs_\ell - \sum_{\ell=1}^{L} xc_{\ell\ell n} \geq 0, \quad \forall \ \ell=1, \ldots, L; \ n=1, \ldots, N \tag{3}$$

$$\sum_{\ell=1}^{L} xc_{\ell\ell n} - \sum_{j=1}^{J}\sum_{k=1}^{K}(\xi_{\ell njk} * x_{\ell jk}) - \sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{k=1}^{K}(\xi_{\ell njk} * xx_{\ell mjk}) \geq 0, \tag{4}$$

$$\forall \ \ell=1, \ldots, L; \ n=1, \ldots, N$$

$$\sum_{\ell=1}^{L} x_{\ell jk} + \sum_{\ell=1}^{L} \sum_{m=1}^{M} xx_{\ell mjk} - y_{jk} \geq 0, \quad \forall\ j=1, \ldots, J;\ k=1, \ldots, K \qquad (5)$$

$$y_{jk},\ s_i,\ x_{\ell jk},\ xx_{\ell mjk},\ xs_{\ell},\ xc_{\ell \ell n} \geq 0 \qquad (6)$$

where:

- i,m,j denote the milk supply, product transshipping, and product demanding regions respectively. The word "regions" is used loosely as a transshipper or a demander need not be a distinct geographic entity. For instance, trading companies, marketing boards, or government agencies within a geographic region may be denoted with a distinct i, m, or j;
- k denotes the products able to be produced from milk;
- ℓ denotes the processing sectors. L is at most equal to I*K. In otherwords, each milk supply region, i, has one processing sector for each product, k, that it produces. Hence, a unique subset of the elements from ℓ correspond to each element of i. A region need not produce all products;
- n denotes the components derived from milk and which are required in the demanded products;
- NW denotes the objective variable to be maximized;
- y_{jk} denotes the quantity of the k^{th} product demanded by the j^{th} region;
- s_i denotes the quantity of raw milk produced at the farm level in the i^{th} region;
- $\theta_{jk}(y_{jk})$ denotes the integral under the inverse internal demand for the k^{th} product in region j, $p^d_{jk}(y_{jk})$, between 0 and y_{jk};
- $\phi_i(s_i)$ denotes the integral under the inverse milk supply of region i, $p^s_i(s_i)$, between 0 and s_i;
- $x_{\ell jk}$ denotes the flow of product k from processor ℓ to region j;
- $xx_{\ell mjk}$ denotes a transshipment flow of product k from processor ℓ to region j via region m, where for each ℓ the associated $i \neq m \neq j$. That is, a transshipping region may not ship product to the region from which it obtained the product, nor may it ship to itself;
- $t_{\ell jk}$ denotes the per unit transportation cost for shipping product k from processor ℓ to region j. Note that the subscripts on t, and also on w, π, and σ, differ slightly for the transshipment flows because there are two arcs associated with such flows;
- w_ℓ denotes the per unit cost to produce product at the ℓ^{th} processor;
- $\pi_{\ell jk}$ denotes the per unit tariff imposed by region j on imports of k from each other region;
- $\sigma_{\ell jk}$ denotes the per unit subsidy imposed by a region on exports of k to each other region;
- xs_ℓ denotes the flow of milk from the farm level in each region to the respective processors. It should be clear that for all ℓ not associated with a particular i, $xs_\ell=0$;
- $xc_{\ell\ell n}$ denotes the movement of the n^{th} milk component between processors within each region. This activity is made necessary by the jointness of production of dairy products and the need to allocate components to the product where they are most valued;
- $\psi_{\ell n}$ denotes the parameter representing the quantities of the n^{th} milk component contained in a unit of milk arriving at the ℓ^{th} processor. Clearly, $\psi_{\ell n}$ may differ across regions;
- $\xi_{\ell njk}$ denotes the parameter representing the quantity of the n^{th} component contained in a unit of the k^{th} product shipped from processor ℓ to region j. Such a formulation allows the composition of products to differ by demand region and ensures that the processing sector

in the supplying region produces the product according to the demand region's specification.

After the model has been solved, the equilibrium farm milk and product demand prices can easily be obtained. Solving equation (7) yields the farm price of milk while equation (8) gives the product demand prices. Actually, with most software packages, the prices can be read from the dual values associated with equations (2) and (5).

$$p_i^s = p_i^s(s_i^*), \quad \forall\ i=1, \ldots, I \tag{7}$$

$$p_{jk}^d = p_{jk}^d(y_{jk}^*), \quad \forall\ j=1, \ldots, J;\ k=1, \ldots, K \tag{8}$$

The product supply prices, *fob* the processing sector, may be computed by subtracting the generalized delivery costs from p_{jk}^d. Alternatively, they can be obtained by summing the values of the components required to produce the product multiplied by the relevant $\xi_{\ell njk}$. As explained below, the Lagrange multipliers associated with equations (3) and (4) may be interpreted as the milk component values.

The supply and demand schedules, of which $p_i^s(s_i^*)$ and $p_{jk}^d(y_{jk}^*)$ are the respective inverses, are restricted to the following general functional form:

$$\text{Quantity} = \alpha + \delta(\text{Price})^\gamma$$

Such a form allows constant ($\delta=0$), linear ($\delta\neq 0$ and $\gamma=1$), constant elasticity ($\alpha=0$, $\delta>0$, and $\gamma\neq 0$), and mixed schedules ($\alpha,\delta,\gamma\neq 0$).

Additional policy instruments may easily be added to this construction. Some that are frequently used in dairy markets can be modeled simply as bounds on variables. For example, production and import quotas are easily introduced as upper bounds. Also, qualitative restrictions, when used as barriers to trade, can be easily included as zero upper bounds on trade flows. Ad valorem tariffs, on the other hand, are relatively more difficult to model within this framework but may be done so via an iterative procedure.

The following equations, (9) through (14), represent a particular subset of the Kuhn-Tucker (K-T) conditions obtained by differentiating equations (1) through (5) with respect to s_i, xs_ℓ, $xc_{\ell\ell n}$, $x_{\ell jk}$, $xx_{\ell mjk}$, and y_{jk} respectively. For the sake of notational lucidity and clarity of discussion, it is assumed that equations (1) through (5) are continuously differentiable, the Lagrangean function corresponding to equations (1) through (6) is concave, and the optimal values of the variables are on the interior allowing the following K-T conditions to be written as equalities. Associated with each constraint there is a Lagrange multiplier, λ. $\lambda_{1,i}$ is associated with constraint (2), $\lambda_{2,\ell n}$ with (3), $\lambda_{3,\ell n}$ with (4), and $\lambda_{4,jk}$ with constraint (5). For this generalized transshipment formulation, the optimal values of the Lagrange multipliers can be interpreted as market prices (Thore, 1991).

$$-p_i^s(s_i^*) + \lambda_{1,i}^* = 0, \quad \forall\ i=1, \ldots, I \tag{9}$$

$$-\lambda_{1,i}^{*} + \sum_{n=1}^{N} (\lambda_{2,\ell n}^{*} * \psi_{\ell n}) = 0, \quad \forall\ \ell=1,\ \ldots,\ L \tag{10}$$

$$-\lambda_{2,\ell n}^{*} + \lambda_{3,\ell n}^{*} = 0, \quad \forall\ \ell=1,\ \ldots,\ L;\ n=1,\ \ldots,\ N \tag{11}$$

$$-(t_{\ell jk} + w_{\ell} + \pi_{\ell jk} - \sigma_{\ell jk}) - \sum_{n=1}^{N} (\lambda_{3,\ell n}^{*} * \xi_{\ell njk}) + \lambda_{4,jk}^{*} = 0, \quad \forall\ \ell=1,\ \ldots,\ L;\ j=1,\ \ldots,\ J;\ k=1,\ \ldots,\ K \tag{12}$$

$$-(t_{\ell mk} + w_{\ell} + \pi_{\ell mk} - \sigma_{\ell mk}) - (t_{mjk} + \pi_{mjk} - \sigma_{mjk}) - \sum_{n=1}^{N} (\lambda_{3,\ell n}^{*} * \xi_{\ell njk}) + \lambda_{4,jk}^{*} = 0, \quad \forall\ \ell=1,\ \ldots,\ L;\ m=1,\ \ldots,\ M;\ j=1,\ \ldots,\ J;\ k=1,\ \ldots,\ K \tag{13}$$

$$p_{jk}^{d}(y_{jk}^{*}) - \lambda_{4,jk}^{*} = 0, \quad \forall\ j=1,\ \ldots,\ J;\ k=1,\ \ldots,\ K \tag{14}$$

These six equations are helpful in discussing the merits of the model presented above. Equations (9) and (14) are relatively self explanatory. From (9) it can be seen that if a supply region, i, produces milk, then the market price of raw milk, $\lambda_{1,i}^{*}$, in the i^{th} region must be equal to the supply price of milk in that region. If the supply price is greater than the market price of milk in region i, no milk will be produced, and by the complementary slackness condition associated with (9), s_i^{*} would equal zero. That is, there would exist a boundary solution. Similarly, (14) indicates that if a demand region, j, receives product k, then the market price of the k^{th} product in the j^{th} region, $\lambda_{4,jk}^{*}$, must equal the demand price of the k^{th} product in the j^{th} region. If the market price of the k^{th} product in region j is greater than the demand price, no product k will be received in region j.

Equation (10) requires that the market price of a unit of milk in any supply region be equal to the sum of the prices of its constituent components each multiplied by the total quantity of those components in that unit of milk, $\sum_{n=1}^{N} (\lambda_{2,\ell n}^{*} * \psi_{\ell n})$, for all milk flows to all processors in that region. Thus, the model will continue to allocate milk among that region's processors and move components between processors, until the market price of a unit of milk and the total value of that unit's components, at each processor, within each region, is equalized. If the total value of the components of a unit of milk, $\sum_{n=1}^{N} (\lambda_{2,\ell n}^{*} * \psi_{\ell n})$, does not attain the market price of milk for that region, $\lambda_{1,i}^{*}$, then no milk is delivered to that processor, that is, xs_{ℓ} equals zero.

Equation (12) requires that the sum of the market prices of the components used by the ℓ^{th} processor to produce a unit of the k^{th} product multiplied by the quantity of components in that product, $\sum_{n=1}^{N} (\lambda^{*}_{3,\ell n} * \xi_{\ell njk})$, plus the generalized delivery cost, $t_{\ell jk} + w_{\ell} + \pi_{\ell jk} - \sigma_{\ell jk}$, is equal to the market price of that product in the j^{th} region, $\lambda^{*}_{4,jk}$. Equation (13) does the same thing for the transshipment flows.

Equation (11) can be seen to indicate that if a component, n, is used by a processor, ℓ, or that processor ships it to another processor, then the market price of that component in the milk-supply — product-processing market, $\lambda^{*}_{2,\ell n}$, must be equal to the market price of that component in the product-processing — product-demand market, $\lambda^{*}_{3,\ell n}$. If the processing to demand market price is less than the milk supply to processing market price, then none of that component will be allocated for use by that processor, that is, $xc_{\ell\ell n}$ equals zero.

The importance of the component based formulation should now be apparent. Consider the market for, say, k=NDM, in the j^{th} region and suppose that some exogenous factor causes a rightward shift of the inverse demand function, $p^{d}_{j,k=NDM}(y_{j,k=NDM})$. By equation (14), ceteris paribus, $\lambda^{*}_{4,jk=NDM}$ must increase. It's already been shown above that the sum of the value of all the components used in a unit of NDM demanded in region j, $\sum_{n=1}^{N} (\lambda^{*}_{3,\ell n} * \xi_{\ell njk})$, and the generalized delivery cost, would also increase because it must equal $\lambda^{*}_{4,jk=NDM}$. Thus, when N, the number of elements in n, is strictly greater than one, the direction of change for the n^{th} $\lambda^{*}_{3,\ell n}$ for all processors shipping NDM to region j is indeterminate. We know only that the summation of the total value, $\sum_{n=1}^{N} (\lambda^{*}_{3,\ell n} * \xi_{\ell njk})$, must increase. However, when there is only one component, that is, N=1, $\lambda^{*}_{3,\ell n}$ is required to increase for all processors shipping NDM to region j but this implies that the prices of all other products will increase, or at least not decrease, as a result of a price increase in the NDM market in region j. Recognizing that in the real world N is indeed greater than one, it is clear that such a result is unrealistic and would lead to false conclusions.

CONCLUSIONS

This paper has discussed some of the important issues that need to be considered when designing a dairy trade model and has presented a model which offers a number of advantages over the typical methods used to formulate spatial trade models. The central feature of the proposed formulation is the method by which a single input, which consists of more than one desired component, may be allocated to the various products which require those components. A mechanism for assigning values to the components of milk is a direct consequence of such a formulation. The difficulties associated with expressing jointly produced products in equivalent units are significantly mitigated with the proposed multi-component formulation. A simple example illustrated how this leads to preferred results.

The model presented allows for the explicit representation of policy instruments which is helpful when decision-makers are expected to use the analytical results to formulate appropriate responses. The model also includes a processing sector, thereby facilitating the specification of the opportunity for arbitrage to occur. This is particularly important in an environment where preferential trading arrangements are common, as is the case in the world dairy market, and especially under the proposed NAFTA. In addition, the inclusion of a processing sector provides the flexibility for improving the model further. For instance, the model could easily allow traded products which are actually intermediate goods to be transformed into final goods which could then be made available for further trade.

One drawback with the proposed formulation is the increased data required to specify the model, although such data are at least measurable if not always readily available. This cost is outweighed, however, by benefits such as the alleviation of the effects of unrealistic restrictions.

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