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Interstate Movements: an Application of Spatial Equilibrium Models

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ABSTRACT: Institutional restrictions were assessed on interstate movements of Australian wheat in a competitive spatial equilibrium model, showing that there would be a substantial potential for interstate movements of wheat if growers had the option of totally free and open borders available.

KEYWORDS: Non-linear programming; Grains; Storage; Handling; Transport; Australia.

1. INTRODUCTION

It seems clear that there is a tendency of Australian State Governments to attempt to retain the highest possible proportion of their States' production for their own rail, port and grain handling systems.

Previous studies on interstate wheat movements have indicated that the existing flows are less than they would be in a deregulated market. Also, it has been shown that changes in institutional arrangements or physical relationships in one part of the distribution system often have significant effects in other connected areas.

Models such as those developed by Kerin (1984, 1985a, 1985b) and the more aggregate transport model developed by Blyth et al. (1987) are useful in determining leastcost grain flow paths for given levels of production in each region.

However, such models are partial in the sense that they provide no information on how farm level output might change as a result of changing the nature of the price incentives facing growers. In addition, it is often difficult to adequately analyze the impact of production or demand uncertainty within the framework of a large transportation model. Therefore, the transportation models are partial in the sense that they take no account of changes in supply and demand as a result of changes in various prices. In other words, supplies and demands are assumed to be perfectly inelastic.

Thus, a spatial equilibrium model is proposed to describe the flow of Australian wheat from supply regions to overseas and domestic consumers, basically representing the arrangements between country silos and Australian ports. With data from the 1985-86 season, the model will be based on supply response and demand functions from previous studies and will assume that the transport of wheat from a local silo to a port is undertaken by rail [Royal Commission into Grain Storage, Handling, and Transport (1988c, 3)].

The base run of the model will be representative of the existing distribution system in that season and will include the institutional barriers to interstate movements of wheat. The main objective will then be to analyze the extent to which interstate flows of wheat will be altered within three different scenarios:

(a) removal of price discrimination;

(b) removal of price discrimination and changes in the supply response of wheat;

(c) removal of price discrimination and substitution for the pooled system of charges by a disaggregated charging system.

The results obtained in each different scenario will be compared to those from the base run so as to provide sufficient and necessary terms to support the opening of the interstate borders to wheat movements.

2. STATEMENT OF THE PROBLEM

Wheat in Australia is a generally homogeneous product, produced in different supply regions and allocated to different demand regions, according to the final use required for the grain. Basically, the supply and demand prices are separated by transportation and handling costs per physical unit of wheat. For each region, functions which relate local production and final demand use to price can be derived. Given these behavioral functions and transport and handling costs, it is possible to determine the final equilibrium prices in all the markets, the amounts of wheat demanded and supplied in each region and the volume and direction of wheat shipments between each possible pair of regions that will maximize the net returns for each source and permit the distribution of wheat at minimum cost.

3. THE PROPOSED MODEL

It is a difficult task to classify the behavior of the Australian wheat industry during the 80s. If one considers that the average costs, as well the prices obtained in the world market, represent actual points on supply and demand schedules under a competitive environment, it could then be said that the marketing arrangements coordinated by a monopolist Board - the Australian Wheat Board - working in conjunction with a monopolistic distribution industry - the State Railway and Handling Authorities - are allowing for a clear transmission of market prices to growers, to those providing services to growers and to users and consumers.

The decision was then to formulate the mathematical structures for both competitive and monopolistic models, and to have separate base runs for each approach. The model that better reproduces the results obtained for the season 1985-86 will be selected for the runs of the policy experiments.

3.1. The perfectly competitive model

The perfectly competitive model can be developed as a maximization problem of the so-called net social revenue (total social revenue less total social costs less distribution costs). The mathematical model proposed by Takayama and Judge (1971) has the following objective function:

$$\mathrm{NSR} = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{m} p^i x_i - \sum_{j=1}^{n}\sum_{i=1}^{m} t_{ij} f_{ij} \qquad (1)$$

where:

- NSR = net social revenue;
- p_j = wheat demand price;
- p^i = wheat supply price;
- y_j = quantity of wheat consumed;
- x_i = quantity of wheat supplied;
- t_{ij} = distribution cost between regions i and j; and
- f_{ij} = quantity transported from region i to region j.

Function (1) will be subject to the following constraints:

(a) Demand Constraints

The typical demand function for each of the n regions can be represented as:

$$y_j = \alpha_j - \beta_j p_j, \qquad j = 1, \ldots, n, \qquad (2)$$

where α_j is the intercept and β_j the slope coefficient for each of the n regions. To guarantee the demand quantity available is not exceeded,

$$y_j \geq \alpha_j - \beta_j p_j, \qquad j = 1, \ldots, n. \qquad (3)$$

If the transfers from supply to meet both intraregional and interregional shipments are considered, then

$$y_j = \sum_{i=1}^{m} f_{ij}, \qquad j = 1, \ldots, n, \qquad (4)$$

so that after the appropriate substitutions of equations (3) into (4),

$$\sum_{i=1}^{m} f_{ij} \geq \alpha_j - \beta_j p_j, \qquad j = 1, \ldots, n, \qquad (5)$$

Rearranging,

$$-\beta_j p_j - \sum_{i=1}^{m} f_{ij} \leq -\alpha_j, \qquad j = 1, \ldots, n, \tag{6}$$

(b) Supply Constraints

The typical supply function for each of the m regions can be represented as:

$$x_i = \theta_i + \gamma_i p^i, \qquad i = 1, \ldots, m, \tag{7}$$

where θ_i is the intercept and γ_i is the slope coefficient for each of the m regions.

To guarantee the supply available is not exceeded,

$$x_i \leq \theta_i + \gamma_i p^i, \qquad i = 1, \ldots, m, \tag{8}$$

As total supply available in a region is equal to the quantity consumed out of its domestic supply plus outward trade flows, then

$$x_i = \sum_{j=1}^{n} f_{ij}, \qquad i = 1, \ldots, m, \tag{9}$$

so that after the appropriate substitutions becomes

$$\sum_{j=1}^{n} f_{ij} \leq \theta_i + \gamma_i p^i, \qquad i = 1, \ldots, m. \tag{10}$$

Rearranging,

$$-\gamma_j p^i + \sum_{j=1}^{n} f_{ij} \leq \theta_i, \qquad i = 1, \ldots, m. \tag{11}$$

(c) Price Arbitrage Constraints

The price arbitrage constraints, are by far the most important ones for the definition of the market structure to be investigated. In a spatially competitive model, to guarantee that the prices between any two regions cannot differ by more than their respective distribution costs, the following constraint must hold:

$$p_j - p^i \leq t_{ij}, \qquad j = 1, \ldots, n, \; i = 1, \ldots, m. \tag{12}$$

a relation that should be valid for any possible combination between one of the n demand regions and one of the m supply regions.

3.2. The monopoly model

The "multiplant monopolist" problem [Greenhut et al. (1987)] has had its mathematical structure developed by Takayama and Judge (1971, 208-31) and Hashimoto (1985, 20-40). However, both sources have treated the problem in a quantity formulation. The price formulation will be developed in the following sections and adapted to include cost functions. The grounds for the use of the price form of the spatial model include, according to the Royal Commission into Grain Storage, Handling and Transport (1988d, 110), "... its small size under regular conditions... and the fact that both prices and quantities enter the solution". The spatial monopoly model will then determine the regional marginal revenues and marginal costs, regional supply and consumption and the interregional trade flows.

Assume the demand, or average revenue function, for the *jth* region is given by

$$y_j \geq \alpha_j - \beta_j p_j, \qquad j = 1, \ldots, n, \tag{13}$$

where α_j is the intercept and β_j the slope coefficient for each of the n regions. When this expression is inverted, it becomes:

$$p_j = \frac{\alpha_j}{\beta_j} - \frac{1}{\beta_j} y_j, \qquad j = 1, \ldots, n, \tag{14}$$

where p_j = average revenue from wheat and y_j = quantity of wheat consumed.

Assuming the coincidence of the supply schedule with the marginal cost schedule at any point above the minimum value of the corresponding variable cost curve [Tomek and Robinson (1981, 74)], the monopolist's marginal cost function for production in each *ith* region can be represented by

$$x_i \leq \theta_i + \gamma_i p^i, \qquad i = 1, \ldots, m, \tag{15}$$

where θ_i is the intercept and γ_i is the slope coefficient for each of the m regions. When this expression is inverted, it becomes:

$$p^i = -\frac{\theta_i}{\gamma_i} - \frac{1}{\gamma_i} x_i, \qquad i = 1, \ldots, m, \tag{16}$$

where p^i = wheat supply price and x_i = quantity of wheat supplied.

The spatial monopoly model can then be developed by assuming that the monopolist industry buys its factors of production in competitive markets (that is, transportation, storage and handling services), is not a monopsonist in the factor market and the resale of the product between regions is not possible so that the monopolist can practice price discrimination. Following Hashimoto (1985, 28), the objective will be then to maximize total profits over all regions where the profit from sales over all the regions is

$$\text{Profit} = \text{Total Revenue - Total Costs, or} \tag{17}$$

$$\Pi = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{m} \int p^i dx_i - \sum_{j=1}^{n} \sum_{i=1}^{m} t_{ij} f_{ij} \tag{18}$$

subject to

$$\sum_{i=1}^{m} f_{ij} \geq y_j, \qquad \text{for all j, and} \tag{19}$$

$$x_i \geq \sum_{j=1}^{n} f_{ij}, \qquad \text{for all i,} \tag{20}$$

where:

Π = total profit;

t_{ij} = distribution cost between regions i and j; and

f_{ij} = quantity transported from region i to region j.

Note that the distribution industry plays a passive role in transferring a given quantity f_{ij} determined by the monopolist, from one region to another, at the fixed unit rate t_{ij}.

Substituting equations (14) and (16) into (18), the Lagrangean function (L) for this maximization problem can be defined as:

$$L = \sum_{j=1}^{n}\left[\left(\frac{\alpha_j}{\beta_j}\right)y_j - \frac{1}{\beta_j}y_j^2\right] - \sum_{i=1}^{m}\left[\left(-\frac{\theta_i}{\gamma_i}\right) + \frac{1}{\gamma_i}\right]dx - \sum_{j=1}^{n}\sum_{i=1}^{m} t_{ij}f_{ij} + \rho_j\left(\sum_{i=1}^{m} f_{ij} - y_j\right) + \rho^i\left(x_i - \sum_{j=1}^{n} f_{ij}\right) \quad (21)$$

The optimality conditions for this maximization problem can be derived through the application of the Kuhn-Tucker conditions [Kuhn and Tucker (1951)], which provide the basis for recognizing candidates for an optimal solution for this non-linear programming problem. Therefore, it can be stated that:

$$\frac{\delta L}{\delta y_j} = \frac{\alpha_j}{\beta_j} - \frac{2}{\beta_j}y_j - \rho_j \le 0 \text{ and } \frac{\delta L}{\delta y_j}y_j = 0, \text{ for all j.} \quad (22)$$

$$\frac{\delta L}{\delta x_i} = \frac{\theta_i}{\gamma_i} - \frac{1}{\gamma_i}x_i + \rho^i \le 0 \text{ and } \frac{\delta L}{\delta x_i}x_i = 0, \text{ for all i;} \quad (23)$$

$$\frac{\delta L}{\delta x_{ij}} = -t_{ij} + \rho_j - \rho^i \le 0 \text{ and } \frac{\delta L}{\delta x_{ij}}f_{ij} = 0, \text{ for all i and j;} \quad (24)$$

$$\frac{\delta L}{\delta \rho_j} = \sum_{i=1}^{m} f_{ij} - y_j \ge 0 \text{ and } \frac{\delta L}{\delta \rho_j}\rho_j = 0, \text{ for all j;} \quad (25)$$

$$\frac{\delta L}{\delta \rho^i} = -\sum_{j=1}^{n} f_{ij} + x_i \ge 0 \text{ and } \frac{\delta L}{\delta \rho^i}\rho^i = 0, \text{ for all i.} \quad (26)$$

Interpreting the Lagrangean multipliers ρ_j and ρ^i as the optimum operative marginal revenue and optimum marginal cost, respectively, the following economic implications, analogous to the quantity formulation of Takayama and Judge (1971, 212), can be taken from equations (22) to (26):

(i) From equation (22): If y_j is equal to zero, the operative marginal revenue of the monopolist is greater than or equal to the marginal revenue in the *jth* market; if y_j is positive, the monopolist's marginal revenue is equal to the marginal revenue in the *jth* region;

(ii) From equation (23): If x_i is equal to zero, the marginal cost to the monopolist is less than or equal to the marginal cost in the *ith* region; if x_i is positive, the monopolist's marginal revenue is equal to the marginal cost in the *ith* region;

(iii) From equation (24): If f_{ij} is equal to zero, the difference ρ_j - ρ^i is less than or equal to the distribution costs between i and j; if x_{ij} is positive, the difference ρ_j - ρ^i is exactly equal to the distribution costs between i and j;

(iv) From equation (25): If ρ_j is equal to zero, the inshipments are greater than or equal to the demand quantity in the *jth* region; if ρ_j is positive, the total amount inshipped is exactly equal to the demand quantity in the *jth* region;

(v) From equation (26): If ρ^i is equal to zero, the supply quantity in the *ith* region is greater than or equal to the outshipments; if ρ^i is positive, the supply quantity in the *ith* region is exactly equal to the outshipments.

A final economic interpretation can be made regarding the objective function (18). If the values of ρ_j and ρ^i are substituted for p_j and p^i in (18), the value obtained for the total profit Π must be equal to zero at the optimum solution (sum of total revenues equal to the sum of total costs), which provides a strong test for the primal-dual symmetry of the model.

Therefore, the price formulation of the monopoly model to be utilized in this study will have the following components:

(a) Objective function

$$\Pi = \sum_{j=1}^{n} p_j y_j - \sum_{i=1}^{m} \rho^i x_i - \sum_{j=1}^{n}\sum_{i=1}^{m} t_{ij} f_{ij} \tag{27}$$

(b) Demand Constraints

From equations (22) and (25),

$$-\frac{\beta_j \rho_j}{2} - \sum_{i=1}^{m} f_{ij} \leq -\frac{\alpha}{2}, \qquad j = 1, \ldots, n, \tag{28}$$

(c) Supply Constraints

From equations (23) and (26),

$$-\gamma_i \rho^i + \sum_{j=1}^{n} f_{ij} \leq \theta_i, \qquad i = 1, \ldots, m. \tag{29}$$

(d) Price Arbitrage Constraints

From equation (24),

$$\rho_j - \rho^i \leq t_{ij}, \qquad j = 1, \ldots, n, \; i = 1, \ldots, m. \tag{30}$$

Note that the distribution costs t_{ij} will be the sum of two different components, namely handling costs and transportation costs. Also, it must be pointed out that in a monopolist model, the market prices between regions may differ by more than the distribution costs and thus the monopolistic pricing system may be quite different from that achieved under perfect competition. To facilitate the comparison, the interregional price relationship can be rewritten.

From (22),

$$\rho_j = \frac{\alpha_j}{\beta_j} - \frac{2}{\beta_j} y_j, \qquad j = 1, \ldots, n, \tag{31}$$

Combining (31) with (14),

$$\rho_j = p_j - \frac{1}{\beta_j} y_j, \qquad j = 1, \ldots, n, \tag{32}$$

Substituting (32) into (30),

$$p_j - \rho^i \leq t_{ij} + \frac{1}{\beta_j} y_j, \qquad j = 1, \ldots, n, \; i = 1, \ldots, m. \tag{33}$$

Therefore, the interregional price relationship in the monopoly model is such that the difference between the demand price in consuming region j and the marginal production cost in production region i is equal to the sum of the distribution cost t_{ij} plus the margin described by $(1/\beta_j)\, y_j$.

4. METHOD

The general mathematical formulation for a both monopoly and competitive spatial equilibrium model is applied to the Australian wheat industry, that was divided into 19 supply regions and 34 demand destinations. The approach utilized will permit the incorporation of the primal-dual structure developed by Takayama and Judge (1971) and the optimal solution will be obtained by using a reduced-gradient method incorporated into the non-linear programming computer code known as MINOS [Murtagh and Saunders (1987)].

To achieve the objectives stated for this study, the following scenarios were specified:

Scenario A (Base run): national competitive and monopolistic models to be developed and barriers to interstate movements of wheat to be represented by the closure of the borders. The most accurate model (competitive or monopolistic) will be used for the remaining scenarios.

Scenario B (Removal of price discrimination): a national model to be developed, with the State borders open to the potential interstate movements of wheat. This will provide a way of evaluating the difference between the most economic routes and State boundaries as determinants of distribution paths for Australian wheat.

Scenario C (Removal of price discrimination and changes in the supply response of wheat): selected supply response elasticities used in scenario B to be parameterized and the interstate movements for each solution to be compared.

Scenario D (Removal of price discrimination and substitution for the pooling system of charges by a disaggregated charging system): the Royal Commission into Grain Storage, Handling and Transport (1988b) developed the average country operating handling cost functions for the States of New South Wales and South Australia and operating handling cost functions for each Australian port. Analogous functions will be developed according to the regional classification used for the study. The main difference, in terms of the structure of the general spatial equilibrium model, will rely on the alteration of the equations (12) and (30), that will become:

$$p_j - p^i \leq g(f_{ij}), \qquad j = 1, \ldots, n, \; i = 1, \ldots, m. \tag{34}$$

$$\rho_j - \rho^i \leq g(f_{ij}), \qquad j = 1, \ldots, n, \; i = 1, \ldots, m. \tag{35}$$

where $g(f_{ij})$ is the non-linear average distribution cost function to which the wheat supplied by region i and delivered to region j is subject [see MacAulay et al. (1988) for a more extensive development of this case]. In incorporating $g(f_{ij})$ as a quadratic function a cubic programming model results. As discussed by Takayama (1993), to some extent, this type of experience corroborates to expel the bias towards quadratic programming formulation of spatial equilibrium models.

5. RESULTS

The supply prices obtained by the competitive model were higher than those from the monopoly model. This is a consequence of an inelastic operative marginal cost curve and a more elastic marginal revenue curve. On the demand side, the competitive model generated the lowest demand price of the two models. This can be explained if equations (12) and (33), the "price arbitrage conditions" for each model, are compared. When trade takes place between regions in the competitive model, the price differentials in the supply and demand regions are made up only of distribution costs. In the monopolistic model, a margin is added to the distribution costs. These margins are directly proportional to the total demand quantities of the demand regions and inversely related to the slopes of the demand functions. For instance, because human consumption and stockfeed demand functions had very steep slopes, resulting from their corresponding small elasticities, the margins obtained for those cases were extremely large, making the monopolistic demand prices much greater than the competitive ones. Therefore, the interregional price relationships generated different trade flows and demand prices between the two models.

Commenting on the export figures, the wheat movements through each different port did not match the actual observation in the season of study. This fact suggests that either the port allocation by the Australian Wheat Board was not done according to competitive rules or that the regional basis used was not the most suitable one. With regard to the latter, Heady (1963) suggests that the problem arises because of aggregation and related problems of interregional competition. The same author reports, what was clearly noticed in this study, about the difficulty in determining the optimum extent of aggregation over commodities, inputs and regions. Perhaps, if the number of supply regions was increased, a better approximation could be obtained for the disposal of wheat to each Australian port. However, as Heady (1963, 129) mentions, "... the intensity of the aggregation problem is, partly, a function of the purposes of investigation". In the competitive spatial equilibrium model proposed, the main concern is to assess the movements across the State borders and the level of aggregation adopted is considered appropriate.

Nevertheless, if it is considered that the competitive spatial equilibrium model was validated as a satisfactory representation of the system, the port allocations utilized by the Australian Wheat Board could profitably be modified. For instance, port facilities at Adelaide, Port Lincoln and Port Pirie were sufficient to meet the export demand needs for the season 1985-86 in South Australia. Similarly, Albany, Geraldton and Kwinana were sufficient to export the wheat production in Western Australia.

Overall, the competitive model not only ratified the production and consumption patterns of the 1985-86 season but also revealed that there were alternative paths that could also lead to efficient allocation of resources by the wheat marketing and distribution authorities.

5.1. Policy experiments

After comparison with a monopoly spatial model, the competitive version of the spatial equilibrium model was considered not only appropriate for the base run (scenario A, no interstate movements) as certainly for the runs of scenarios B, C and D, in which trade between the States was permitted to make possible the analysis of the extent to which interstate movements have been suppressed. To represent the season 1985-86, secondary data from various sources, including supply and demand elasticities, were used in the development of the various scenarios.

All the results obtained with the "open border" scenarios (including scenario D, where a representation of disaggregated charging for handling and storage services is treated) had in common the fact that approximately 2.1 million tones of wheat produced in New South Wales were allocated to Queensland (1.0 million tones through Brisbane) and Victoria (1.1 million tones through Geelong). These results would seem to provide a useful base for the pertinent policy analysis and recommendations.

6. CONCLUDING REMARKS

The modeling work developed in this study had as its basic aim the provision of a tool to help the establishment of possible lines of inquiry for eventual new policy implementations for the Australian wheat industry, as well to offer a general modeling structure for assessment of the potentiality of inter-border movements. Running the policy experiments for the investigation of potential interstate movements, a spatial price equilibrium was achieved for the fictitious option of trade between States. The results obtained showed that there would be a very large potential for interstate movements of wheat if growers had the option of totally free and open borders available. The greatest advantages would go to the New South Wales' farmers located close to the Queensland and Victorian borders.

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