2 Prices over space

2.1 Introduction

The purpose of this chapter is to examine how the set of competitive prices for a particular commodity at a particular point in time are connected over space. Prices will be spatially integrated if commodity deficit and commodity surplus regions trade amongst themselves and profit seeking arbitrage results in the LOP. Arbitrage implies that profit-seeking traders will ship the commodity from a low-price exporting region to a high-price importing region if the price difference exceeds the marginal transportation and handling costs. These arbitrage shipments, which serve to raise the price in the exporting region and to lower the price in the importing region, will continue until the price difference is reduced to the marginal transportation cost.[1] The assumption of competitive prices may appear to be unreasonable because agricultural commodity trade is often dominated by large multinational firms and state trading agencies. Nevertheless, easy entry by small traders and heavily traded futures markets is believed to be sufficient to ensure reasonably competitive pricing for the major agricultural commodities.

A simple example will illustrate several important features of prices over space and the spatial version of the LOP. Table 2.1 shows ocean freight rates as of 23 November 2005 for a set of exporting and importing regions. There is considerable variation in shipping rates, varying from a low of \$19/tonne when Australia sells to South Korea to a high of \$45/tonne when the US sells to South Korea. Figure 2.1 shows a scenario where Australia and the US export hard red winter (HRW) wheat to Egypt and South Korea. The numbers associated with each pair of countries are the transportation cost data from Table 2.1 and the numbers associated with each particular country are the export/import prices. The US price of \$165/tonne is exogenous and the remaining prices are endogenous. The \$165/tonne value corresponds to the price of HRW #2 11.5 percent protein wheat at the US Gulf Coast on 23 November 2005.[2]

Figure 2.1 implies that a US exporter could profitably purchase Gulf Coast wheat and sell into Egypt provided that the Egyptian import price was 165 + 35 = \$200/tonne or better (the freight cost from the US Gulf to Egypt is \$35/tonne).[3] Assuming that competition by US exporters bids the price of wheat in Egypt down to \$200/tonne, an Australian exporter could profitably sell to Egypt provided that

Table 2.1 Ocean freight rates for grain, select ports, 23 November 2005

US dollars per tonne					
From↓/To→	*Algeria*	*Egypt*	*Iran*	*Korea*	*Morocco*
Australia	na	32	29	19	na
EU	24	26	na	na	22
US Gulf	na	35	Na	45	32

Source: Market Data Center: http://data.hgca.com/demo/archive/physical/xls/Ocean%20Freight%20Rates.xls

Note: "na" indicates that data are not available.

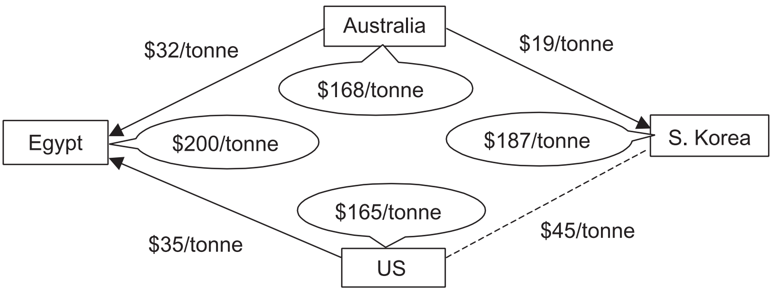

Figure 2.1 Prices and trading partners in a simple spatial price example.

the Australian export price for the same quality wheat was 200 − 32 = $168/tonne or lower (the freight cost from Australia to Egypt is $32/tonne). If there are sizeable stocks of wheat moving from Australia to Egypt, then competition by Australian exporters would bid the Australian export price up to $168/tonne. Based on this price, an Australia exporter could also land wheat in South Korea at cost of 168 + 19 = $187/tonne (i.e., the cost of transporting wheat between Australia and South Korea is $19/tonne). With a landed Australian price in South Korea equal to $187/tonne, a US exporter cannot compete in the South Korean market because a minimum price of 165 + 45 = $210/tonne is required for a US exporter to make a profit (i.e., the transport cost between the US and Korea is $45/tonne).

The data in Table 2.1 reveal several additional relationships between equilibrium prices and transportation costs. For example, if the EU is simultaneously exporting to Egypt and Morocco, then the long-run equilibrium price in Egypt should be higher than the long-run equilibrium price in Morocco by $4/tonne because of the $4/tonne cost advantage that Morocco enjoys when purchasing from the EU. Similarly, if Australia is also exporting to Egypt, then the export price in Australia should be $6/tonne lower than the EU export price because of the $6/tonne cost advantage that the EU enjoys over Australia when exporting to Egypt. A $6/tonne price difference between Australia and the EU implies that these two regions will not trade with each other because the $6/tonne profit that could be made through trade is likely to be insufficient to cover the cost of shipping grain from Australia to the EU.

The purpose of this chapter is to illustrate how interregional trade can be modeled for the case of a perfectly homogenous commodity where price alone fully determines buying and selling patterns. The model consists of a group of exporting and importing regions with unique distances separating the various regions. In equilibrium, a particular exporter will ship to a subset of the nearest importers and a particular importer will purchase from a subset of the nearest exporters.[4] The key feature of the LOP outcome is that: (1) for any pair of trading regions the import and export price difference is equal to the unit cost of transportation; (2) for any pair of exporters selling to the same importer (or for any pair of importers buying from the same exporter), the absolute difference in the pair of export prices (or the pair of import prices) is equal to the absolute difference in the unit cost of transportation; and (3) the absolute price difference between any pair of countries that are not trading with each other will not exceed the unit transportation cost between that pair of countries.

Solving for the equilibrium set of prices by imposing the LOP restriction directly would be both complicated and time consuming because of the potentially large number of different combinations of trading partners. Fortunately, a simple and effective indirect method exists for obtaining the set of equilibrium prices. The method involves constructing a net aggregate welfare function by aggregating consumer and producer surplus across all trading regions and then subtracting from this value the aggregate cost of transportation. The set of shipment quantities that maximize net aggregate welfare subject to a variety of market clearing and non-negativity constraints can be substituted into the set of inverse supply and demand schedules to recover the set of competitive equilibrium prices. This technique of deriving the set of competitive equilibrium prices by maximizing a net aggregate welfare function works because of Adam Smith's "invisible hand" hypothesis. Indeed, a competitive allocation of the commodity across regions by profit-seeking traders leads to maximum net aggregate welfare, so if maximum net aggregate welfare is obtained through optimization, the associated set of prices must correspond to a competitive market outcome.

Maximizing net aggregate welfare to solve for the set of interregional shipments and prices can be complicated when there are many importing and exporting regions because equilibrium trade will be zero for many pairs of countries. These zero-trade outcomes are referred to as "corner solutions" in the language of mathematical programming. If there are a large number of corner solutions then it will be necessary to solve the pricing problem numerically using relatively sophisticated optimization software.[5] Fortunately, Microsoft Excel has a powerful "Solver" tool that can handle small and medium sized numerical optimization problems. The standard version of Solver can also be upgraded if the model is particularly large (i.e., containing dozens of importers and exporters, which results in hundreds of shipment choice variables).

Before proceeding with the construction of the spatial pricing model, it is useful to discuss the specific uses of this type of analysis. First, spatial analysis can be used to predict location-specific price premiums and discounts. As rising world energy prices increase transportation costs, these premiums and discounts will grow in magnitude and become an increasingly important determinant of a region's level of competitiveness. Second, spatial price analysis can be used to illustrate how a change in supply or demand in one region can cause a domino effect that changes the pattern of shipments and prices in a significant and often unpredictable way. Finally, spatial price analysis can be used for strategic decision making by either corporations (e.g., where is the best location for a terminal elevator?) or policy makers (e.g., what are the predicted price impacts of India and Vietnam's February 2008 embargo on rice exports?).

It should be noted that many economists empirically test whether the predictions made by spatial equilibrium models are observed in reality. More specifically, economists are interested in the degree of spatial pricing integration, which is a measure of the time it takes for markets to adjust to the LOP after a regional price shock. Regional markets in developed market economies such as soft white winter wheat in Bannister, Missouri and Commerce, Colorado tend to be well integrated (see Figure 1.4). However, even in emerging markets such as China, prices for agricultural commodities reveal a surprisingly high degree of integration and often follow a well defined "transportation gradient".[6]

In times of rapidly changing transportation costs, prices may appear to have a low degree of spatial integration even though the LOP is hard at work. Consider Table 2.2, which shows how ocean freight rates for grain between select countries have changed between May 2008 and May 2009 due to the world financial crisis. The US regularly ships grain to Japan, so according to the LOP the difference between the Japanese import price and the US export price is equal to the US–Japan freight rate that is displayed in Table 2.2. Thus, the price difference for the same grain in export position at the Gulf Coast and import position in Japan is predicted to have changed by as much as \$81/tonne (\$125 − \$44) May 2008 to May 2009.

2.2 Basic model

The model consists of *N* regions that competitively produce, consume and trade a homogenous commodity. To keep things simple assume that there is one price for

Table 2.2 Ocean freight rates for grain, select ports, May 2008–May 2009

	US dollars per tonne		
	May 2009	*Nov. 2008*	*May 2008*
US Gulf to EU	30	20	83
US Gulf to Japan	44	28	125
US Gulf to Algeria	31	26	94
Brazil to EU	40	34	96

Source: "Latest Ocean Freight Rates (Weekly)", International Grains Council: http://www.igc.org.uk/en/grainsupdate/igcfreight.aspx each region because production and consumption occurs at the same location. The ith region has an inverse demand schedule, $P_i = a_i + b_i Q_i^D$, and an inverse supply schedule, $P_i = \alpha_i + \beta_i Q_i^S$, where P_i is the price paid by commodity buyers and received by commodity suppliers, and Q_i^D and Q_i^S represent the respective demand and supply quantities. If region i does not produce the commodity in question, then $\alpha_i = \beta_i = 0$. Similarly, if there is no consumption of the commodity then $a_i = b_i = 0$

Let $T_{ij} \geq 0$ denote the amount of commodity shipped from region i to region j. In equilibrium, total shipments out of region i (including sales to buyers within the region) cannot exceed production, which implies the following supply restriction: $\sum_{j=1}^{N} T_{ij} \leq Q_i^S$. Similarly, total shipments into region j (including purchases from suppliers within the region) must be at least as large as regional demand, which implies the following demand restriction: $\sum_{i=1}^{N} T_{ij} \geq Q_j^D$.

Let C_{ij} denote the cost of shipping a unit of the commodity from region i to region j. Unique values can be assigned to the symmetric parameter pairs C_{ij} and C_{ji}, but for the purpose of this study it is assumed that $C_{ij} = C_{ji}$. The LOP implies that if region i is actively shipping to region j, then it must be the case that $P_j = P_i + C_{ij}$. This condition ensures that a trader cannot profitably purchase a unit of the stock in region i at price P_i, pay for the transportation cost, C_{ij}, and then resell the stock in region j at price P_j. If region i is not exporting to region j, then trading must not be profitable, which implies $P_j < P_i + C_{ij}$.

Welfare measurement on a diagram

Recall that the set of competitive equilibrium prices can be obtained by maximizing net aggregate welfare, which is equal to consumer and producer surplus aggregated across the N regions less aggregate transportation expense. Figure 2.2 illustrates the measurement of net aggregate welfare for the case of two trading regions. The left-hand graph represents the commodity exporter (E) and the right-hand graph represents the commodity importer (I). The middle graph shows the export supply curve of E, which is derived as the horizontal difference between the supply and demand schedules within E. The middle graph also shows the import demand schedule for I, which is derived as the horizontal difference between the demand and supply schedules within I. The export supply schedule for E is shifted up by an amount C_{EI} to account for the cost of transporting the commodity.[7]

The intersection of the raised export supply schedule with the import demand schedule in the middle graph of Figure 2.2 shows the equilibrium level of trade between the two regions, T_{EI}.

Figure 2.2 also shows that the equilibrium price in E is P_E, which leads to consumption at level Q_E^D and production at level Q_E^S, where $Q_E^S - Q_E^D = T_{EI}$. As well, the equilibrium price in I is P_I, which leads to consumption at level Q_I^D and production at level Q_I^S, where $Q_I^D - Q_I^S = T_{EI}$. Figure 2.2 conforms to the LOP, which requires $P_I - P_E = C_{EI}$.

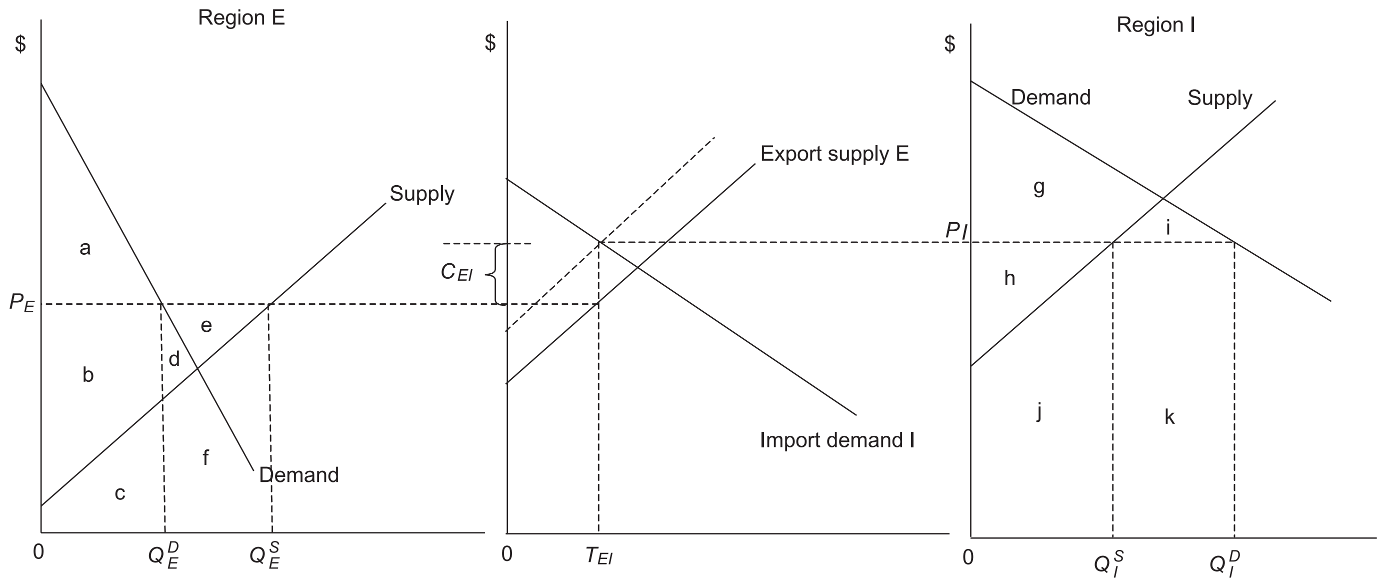

Figure 2.2 Measurement of net aggregate welfare in a spatial equilibrium model.

After trade, consumers in E earn surplus given by area *a* and producers in E earn surplus given by area $b + d + e$. The combined surplus of consumers and producers is therefore equal to area $a + b + d + e$. Similarly, consumers in I earn surplus given by area $g + i$ and producers in I earn surplus given by area *h*. The combined surplus of consumers and producers is therefore equal to area $g + h + i$. Aggregating across both regions implies that net aggregate welfare is given by area $a + b + d + e + g + h + i$.

Net aggregate welfare can also be measured in a way that will prove useful in the optimization model. The first step is to aggregate the areas under the two demand schedules, up to Q_E^D for E and Q_I^D for I. The second step is to aggregate the areas under the two supply schedules, up to Q_E^S for E and Q_I^S for I. To complete the calculation of net aggregate welfare, subtract the latter measure from the former, and then subtract aggregate transportation cost, $C_{EI}T_{EI}$.[8] To establish that this measure is the same as that derived in the previous paragraph, notice from Figure 2.1 that the combined area under the two demand schedules is given by $a + b + c + g + h + i + j + k$ and the combined area under the two supply schedules is given by $c + f + j$. Hence, net aggregate welfare under the proposed scheme is given by area $a + b + g + h + i + k - f - C_{EI}T_{EI}$.

However, as Figure 2.2 shows, area *k* is equal to area $d + e + f + C_{EI}T_{EI}$. After substituting this expression for *k* into the previous equation, the revised area for net aggregate welfare is given by $a + b + d + e + g + h + i$. This outcome agrees with the area for net aggregate welfare, which was derived in the previous paragraph.

Assumptions for mathematical model

To construct a mathematical model it is necessary to assign specific functional forms to the regional supply and demand schedules and then obtain expressions for the aggregate areas under these schedules. Assuming a linear inverse demand schedule for region *i*, $P_i = a_i - b_iQ_i^D$, the formula for the area under the demand schedule is $0.5(a_i - P_i)Q_i^D + P_iQ_i^D$, which becomes $(a_i - 0.5b_iQ_i^D)Q_i^D$ after substituting the demand schedule for P_i. The inverse supply schedule for region *i* given by, $P_i = \alpha_i + \beta_iQ_i^S$. If this schedule intersects the vertical axis at a positive price, then the area under the supply schedule for region *i* is $\alpha_i Q_i^S + 0.5\ (P_i - \alpha_i)Q_i^S$, which becomes $(\alpha_i + 0.5\beta_iQ_i^S)Q_i^S$ after substituting the supply schedule for P_i. Conversely, if the supply schedule intersects the horizontal axis at a positive quantity, then the area under the supply schedule is $0.5(Q_i^S - Q_i^0)P_i$, where $Q_i^0 = -\alpha_i/\beta_i$ is the point of intersection. After making this substitution, along with $P_i = \alpha_i + \beta_iQ_i^S$ for P_i, the formula for the area under the supply schedule for the case of a horizontal axis intersection can be written as $0.5(\alpha_i + \beta_iQ_i^S)\left(Q_i^S + \alpha_i/\beta_i\right)$.

For an arbitrary set of values for Q_i^D, Q_i^S and T_{ij}, and with the supply schedules intersecting the vertical axes at a positive price, the measure of net aggregate welfare (NAW) for all *N* regions can be expressed as:

$$NAW_V = \sum_{i=1}^{n}\left(a_i - 0.5b_iQ_i^D\right)Q_i^D - \sum_{i=1}^{n}\left(\alpha_i + 0.5\beta_iQ_i^S\right)Q_i^S - \sum_{i=1}^{n}\sum_{j=1}^{n}C_{ij}T_{ij} \qquad (2.1a)$$

Similarly, if the supply schedules intersect the horizontal axes, the appropriate expression for *NAW* is:

$$NAW_H = \sum_{i=1}^{n}\left(a_i - 0.5b_iQ_i^D\right)Q_i^D - \sum_{i=1}^{n}.5\left(\alpha_i + \beta_iQ_i^S\right)$$

$$\left(Q_i^S + {\alpha_i}/{\beta_i}\right) - \sum_{i=1}^{n}\sum_{j=1}^{n}C_{ij}T_{ij} \qquad (2.1b)$$

The spatial pricing equilibrium can be obtained by choosing the set of values for T_{ij}, Q_i^D and Q_i^S that maximize equation (2.1) subject to the import demand restriction $\sum_{j=1}^{N}T_{ji} \geq Q_i^D$ for all i, the export supply restriction $\sum_{j=1}^{N}T_{ij} \leq Q_i^S$ for all i, and the non-negativity restrictions for T_{ij}, Q_i^D and Q_i^S.

Kuhn–Tucker solution

Before describing the numerical optimization procedures for solving a spatial equilibrium pricing problem, it is useful to first use Kuhn–Tucker programming to derive the LOP relationships. To begin this process it is necessary to construct a Lagrangian function for maximizing net aggregate welfare subject to the various constraints. It is important that the constraints are entered as "less-than-or-equal-to" inequalities, $Q_i^D - \sum_{j=1}^{N}T_{ji} \leq 0$, $\sum_{j=1}^{N}T_{ij} - Q_i^S \leq 0$ and $-T_{ij} \leq 0$, to ensure that the multiplier variables have the correct sign. For the case where the supply schedule intersects the vertical axis the Lagrangian function can be written as:

$$L = \sum_{i=1}^{n}\left[\left(a_i - 0.5b_iQ_i^D\right)Q_i^D - \left(\alpha_i + 0.5\beta_iQ_i^S\right)Q_i^S\right] - \sum_{i=1}^{n}\sum_{j=1}^{n}C_{ij}T_{ij}$$

$$+\sum_{i=1}^{N}\lambda_i^D\left(\sum_{j=1}^{N}T_{ji} - Q_i^D\right) + \sum_{i=1}^{N}\lambda_i^S\left(Q_i^S - \sum_{j=1}^{N}T_{ij}\right) - \sum_{i=1}^{n}\sum_{j=1}^{n}\lambda_{ij}^T T_{ij} \qquad (2.2)$$

The set of λ^D and λ^S variables are the Lagrangian multipliers associated with the import demand and export supply adding-up restrictions, and the set of λ^T variables are the Lagrangian multipliers associated with the $T_{ij} \geq 0$ non-negativity restrictions.

The Kuhn–Tucker conditions for the constrained optimization problem are for $i = 1, 2, \ldots, N$:

$$\partial L \big/ \partial Q_i^D = a_i - b_i Q_i^D - \lambda_i^D \le 0, \quad \left(\partial L \big/ \partial Q_i^D \right) Q_i^D = 0 \quad \text{and}$$

$$\lambda_i^D \left(\sum_{j=1}^{N} T_{ji} - Q_i^D \right) = 0 \tag{2.3a}$$

$$\partial L \big/ \partial Q_i^S = -\left(\alpha_i + \beta_i Q_i^S \right) + \lambda_i^S \le 0, \quad \left(\partial L \big/ \partial Q_i^S \right) Q_i^S = 0 \quad \text{and}$$

$$\lambda_i^S \left(\sum_{j=1}^{N} T_{ij} - Q_i^S \right) = 0 \tag{2.3b}$$

$$\partial L \big/ \partial T_{ij} = -C_{ij} + \lambda_j^D - \lambda_i^S - \lambda_{ij}^T \le 0, \quad \left(\partial L \big/ \partial T_{ij} \right) T_{ij} = 0 \quad \text{and}$$

$$\lambda_{ij}^T T_{ij} = 0 \ \text{for}\ j = 1, 2, \ldots, N \tag{2.3c}$$

Additional restrictions include the resource constraints, $\sum_{j=1}^{N} T_{ji} \ge Q_i^D$ and $\sum_{j=1}^{N} T_{ij} \le Q_i^S$ for $i = 1, 2, \ldots, N$, and non-negative values for all of the multiplier variables.

The consumer and producer price in region i can be expressed as $P_i^D = a_i - b_i Q_i^D$ and $P_i^S = \alpha_i + \beta_i Q_i^S$, respectively. It follows from equations (2.3a) and (2.3b) that $\lambda_i^D = P_i^D$ and $\lambda_i^S = P_i^S$. Producers will sell to domestic consumers before exporting, and consumers will buy from local producers before importing because, by assumption, $C_{ii} = 0$ and $C_{ij} > 0$ for $i \# j$. Using equation (2.3c), the combination of $T_{ii} > 0$ and $C_{ii} = 0$ implies $\lambda_{ii}^T = 0$ and $\lambda_i^D = \lambda_i^S$. This result, combined with $\lambda_i^D = P_i^D$ and $\lambda_i^S = P_i^S$ implies that $\lambda_i^D = \lambda_i^S = P_i^*$. That is, the price is the same for domestic consumers and producers when stocks are optimally allocated by a social planner.

For interregional shipments there are two possibilities. First, using the last expression in equation (2.3c), if region i ships to region j then $T_{ij} > 0$ and $\lambda_{ij}^T = 0$. Using the second expression in equation (2.3c), the $T_{ij} > 0$ result implies that the first expression in equation (2.3c) must hold as an equality. Thus, if $\lambda_{ij}^T = 0$ along with $\lambda_i^D = \lambda_i^S = P_i^*$ are substituted into the first expression in equation (2.3c) it follows that $P_j^* - P_i^* = C_{ij}$. This result confirms the first property of the intertemporal version of the LOP. The second possibility is that region i does not ship to region j, which implies from the last expression in equation (2.3c) that $T_{ij} = 0$ and $\lambda_{ij}^T \ge 0$. The first two expressions in equation (2.3c), combined with $\lambda_i^D = \lambda_i^S = P_i^*$, therefore imply that $P_j^* - P_i^* \le C_{ij}$. This result, that shipments are zero when the price difference is less than the unit transportation cost, confirms the second property of the intertemporal version of the LOP.

The Kuhn–Tucker approach to solving for equilibrium prices works well for small problems, but becomes difficult to implement for large problems. Numerical optimization procedures are typically used for spatial price analysis. These procedures are illustrated below in a case study involving the global trade in tomatoes. Before describing the specifics of this case study, a method for scaling the values of price and quantity variables is described.

Scaling procedure

Numerical optimization works best if the variables of the model have values that are roughly the same order of magnitude. To illustrate the scaling procedure consider the generic demand and supply schedules, $P = a - bQ$ and $P = \alpha + \beta Q$, where Q is quantity measured in tons and P is price measured in dollars per ton. Suppose instead quantity is measured in *ktons* and price is measured in *zollars*, where one *kton* is equal to k tons and one *zollar* is equal to z dollars. If one ton is valued at P dollars then one *kton* is valued at kP dollars. Because one dollar is equal to $1/z$ *zollars*, it follows that one *kton* is valued at $(k/z)P$ *zollars*. Letting $\hat{P}$ denote price measured in *zollars* per *kton*, it follows that, $\hat{P} = (k/z)P$, which in turn implies $P = (z/k)\hat{P}$. Similarly, letting $\hat{Q}$ denote quantity measured in *ktons*, it follows that $Q = k\hat{Q}$.

The next step in the scaling procedure is to substitute the expressions for $\hat{P}$ and $\hat{Q}$ into the inverse demand schedule, $P = a - bQ$, and the inverse supply schedule, $P = \alpha + \beta Q$, to obtain scaled demand and supply schedules, $\hat{P} = \hat{a} - \hat{b}\hat{Q}$ and $\hat{P} = \hat{\alpha} - \hat{\beta}\hat{Q}$, where:

$$\hat{a} = {ak}/{z},\ \hat{\alpha} = {\alpha k}/{z},\ \hat{b} = {bk^2}/{z} \text{ and } \hat{\beta} = {\beta k^2}/{z} \tag{2.4}$$

The unit transportation cost parameter, C_{ij}, is measured in dollars per ton, so the scaled transportation cost parameter that is measured in *zollars* per *kton* can be expressed as $\hat{C}_{ij} = (k/z)C_{ij}$. After optimization it is often desirable to present the variables in original units rather than scaled units. Reverse scaling is achieved by multiply all scaled quantities by k, all scaled prices by z/k and all scaled surplus measures by z.[9]

To illustrate the scaling technique with a specific example, suppose the demand schedule is given by $P = 9000 - 0.001Q$, which implies $a = 9000$ and $b = 0.001$. Also suppose that the objective of the scaling is to achieve $\hat{a} = 1$ and $\hat{b} = 0.5$. Given that $\hat{a} = {ak}/{z}$ and $a = 9000$ it follows that $z/k = 9000$ to ensure that $\hat{a} = 1$. Similarly, given that $\hat{b} = {bk^2}/{z}$ and $b = 0.001$ it follows that $z/k^2 = 0.002$ to ensure that $\hat{b} = 0.5$. Solving these two equations together implies $k = 4{,}500{,}000$ and $z = 40{,}500{,}000{,}000$. Therefore, to generate the scaled demand schedule, $\hat{P} = 1 - 0.5\hat{Q}$, all price data should be divided by $z/k = 9000$ and all quantity data should be divided by $k = 4{,}500{,}000$. In a more general model with multiple demand and supply schedules, values for the scaling variables k and z should be chosen to ensure that the revised set of intercept and slope parameters have a similar order of magnitude.

2.3 Spatial pricing case study

The following case study focuses on the global trade in tomatoes. Tomatoes are one of the most important commodities that trade in the global vegetable market. Dominant tomato producers include China, the European Union and the United States. With respect to trade, dominant exporters of fresh tomatoes are Spain, Mexico and the Netherlands, and dominant importers are United States, Germany and France. For this particular case study the global market for tomatoes is broken into five regions: Mexico, the US, Canada, the European Union (EU) and Latin America.

Parameter estimates for the regional tomato supply and demand schedules are borrowed from an earlier paper on the global tomato market.[10] Unfortunately, this paper did not report the values that were assumed for regional transportation costs. Consequently, estimates of ocean freight rates for fresh vegetables were obtaining by calculating the nautical mileage between representative ports within each region and then multiplying these mileage values by a fixed price per ton per mile.[11] The parameters values for regional supply/demand and transportation costs are summarized in Table 2.3(a) and (b). Negative values for the intercept

Table 2.3 Pre-scaled parameters for tomato case study. (a) Supply and demand intercept and slope parameters; (b) transportation cost parameters

(a)

	Intercept parameters		*Slope parameters*	
Region	*Supply (α)*	*Demand (a)*	*Supply (β)*	*Demand (b)*
Mexico	−2,532	8,732.3	0.00146	0.00578
US	−1,279	2,217.1	0.00021	0.00011
Canada	−2,128	5,131.1	0.0059	0.00581
EU	−5,337	4,258.7	0.00043	0.00022
L. Amer.	−3,306	2,806.5	0.00059	0.00036

(b)

	US dollars per ton				
Region	*Mexico*	*US*	*Canada*	*EU*	*L. Amer.*
Mexico	0.00	58.50	96.63	155.55	161.88
US	58.50	0.00	42.21	106.98	142.05
Canada	96.63	42.21	0.00	106.47	164.43
EU	155.55	106.98	106.47	0.00	137.37
L. Amer.	161.88	142.05	164.43	137.37	0.00

Source:

(a) See endnote 10.

(b) Representative cities are Veracrux (Mexico), New York (USA), Montreal (Canada), Valencia (Spain/EU) and Rio de Janeiro (Brazil/Latin America). Nautical sea mileage between these port cities was obtained from the Sea Rates.Com website: http://www.searates.com/reference/portdistance
The values in (b) were derived by multiplying the nautical mileage by $0.03 per mile.

parameters of the supply schedules imply that these schedules intersect the horizontal axis. Equation (2.1b) rather than (2.1a) must therefore be used to calculate net aggregate welfare.

Model setup

Figure 2.3 illustrates both the setup of the spatial model and the post optimization equilibrium outcome. Cells B5:E9 contained scaled parameter values for the regional supply and demand schedules and cells B13:F17 contain the scaled unit transportation costs. Scaling was achieved by using equation (2.4) and $\hat{C}_{ij} = (k/z)C_{ij}$ together with $k = 1{,}000{,}000$ (i.e., one *kton* is equal to a million tons) and $z = 5{,}000{,}000{,}000$ (i.e., one *zollar* is equal to five billion dollars). To properly interpret the transportation cost matrix given by cells B13:F17 note that the cost of shipping from region i to region j is found by looking up region i in cells A13:A17 and looking up region j in cells B12:F12. The unit transportation cost when the product is shipped from region i to region j can now be found where the ith row and jth column intersect. For example, the value in cell E13 represents the cost of shipping a unit of tomatoes from Mexico to the EU.

The T_{ij} shipment variables that are optimally chosen by Excel (more details below) are listed in cells B21:F25 of Figure 2.3. The shipping regions are identified in column A and the receiving regions are identified in row 20. The total shipments leaving each region (including self-shipments) are shown in cells G21:G25 and the total shipments arriving in each region (including self-purchases) are shown in cells B26:F26. The set of shipment outflow values in cells G21:G25 are repeated in cells B31:B35 (labeled "Supply") and the transpose of the set of shipment inflow values in cells B26:F26 are repeated in cells D31:D35 (labeled "Demand"). This procedure implies that the trade constraints, $\sum_{j=1}^{N} T_{ij} \leq Q_i^S$ and $\sum_{j=1}^{N} T_{ji} \geq Q_i^D$, automatically hold as equalities. Restricting these constraints to equalities rather than inequalities is acceptable because for the problem at hand there is no economic payoff to selling less than what is produced or consuming less than what is purchased.

The set of $\hat{Q}^S$ values in cells B31:B35 and the set of $\hat{Q}^D$ values in cells D31:D35 of Figure 2.3 can now be inserted into the pair of equations $\hat{P}^S = \hat{\alpha} + \hat{\beta}\hat{Q}^S$ and $\hat{P}^D = \hat{a} - \hat{b}\hat{Q}^D$ in order to generate demand and supply prices for each region. The pre-scaled version of these prices are reported in cells C31:C35 and E31:E35 of Figure 2.3 using the formulas $(\hat{\alpha} + \hat{\beta}\hat{Q}^S)^Z/_k$ and $(\hat{a} - \hat{b}\hat{Q}^D)^Z/_k$. The combined surplus for consumers and producers that appears in cells F31:F35 of Figure 2.3 was calculated using equation (2.1b). Gross aggregate welfare, which is the sum of the surplus values in cells F31:F35, is shown in cell D38. The aggregate cost of transportation for all shipments, which is shown in cells D39, is subtracted from gross aggregate welfare to give a measure of net aggregate welfare in cell D40.[12]

	A	B	C	D	E	F	G
1							
2							
3		**Intercept Parameters**		**Slope Parameters**		Scale (k)	1,000,000
4	Country	Supply	Demand	Supply	Demand	Scale (z)	5,000,000,000
5	Mexico	-0.506	1.746	0.292	1.156		
6	U.S.	-0.256	0.443	0.042	0.022		
7	Canada	-0.426	1.026	1.180	1.162		
8	EU	-1.067	0.852	0.086	0.044		
9	L. Amer.	-0.661	0.561	0.118	0.072		
10							
11	**Unit Transport Costs (zollars/kton; zollar =$5,000,000; kton= 1,000,000 tons)**						
12		Mexico	U.S.	Canada	EU	L. Amer.	
13	Mexico	0.00000	0.01170	0.01933	0.03111	0.03238	
14	U.S.	0.01170	0.00000	0.00844	0.02140	0.02841	
15	Canada	0.01933	0.00844	0.00000	0.02129	0.03289	
16	EU	0.03111	0.02140	0.02129	0.00000	0.02747	
17	L. Amer.	0.03238	0.02841	0.03289	0.02747	0.00000	
18							
19	**Shipments Solution Matrix (ktons)**						
20		Mexico	U.S.	Canada	EU	L. Amer.	Total
21	Mexico	1.3622	0.9604	0.0000	0.0000	0.0000	*2.323*
22	U.S.	0.0000	10.4596	0.0000	0.0000	0.0000	*10.460*
23	Canada	0.0000	0.0000	0.5200	0.0000	0.0000	*0.520*
24	EU	0.0000	0.0000	0.0000	14.5298	0.0000	*14.530*
25	L. Amer.	0.0000	0.3952	0.2014	0.6788	5.6422	*6.918*
26	Total	*1.362*	*11.815*	*0.721*	*15.209*	*5.642*	
27			=(B5+D5*B31)*$G$4/$G$3			=(C5-E5*D31)*$G$4/$G$3	
28	**Equilibrium Calculations**						
29	=G21	*Supply (ktons)*		*Demand (ktons)*		*Surplus (zollars)*	
30		Quantity	P ($/ton)	Quantity	P ($/ton)		
31	Mexico	2.323	858.92	1.362	858.93	1.256	
32	U.S.	10.460	917.51	11.815	917.43	3.303	
33	Canada	0.520	939.81	0.721	939.81	0.423	
34	EU	14.530	912.80	15.209	912.82	7.671	
35	L. Amer.	6.918	775.38	5.642	775.32	1.919	
36	=C5*D31-0.5*E5*D31^2-0.5*(B5+D5*B31)*(B31+B5/D5)						
37							
38	Gross Aggregate Welfare (zollars)			14.572	=SUM(F31:F35)		
39	Aggregate Transport Cost (zollars)			0.04774	{=SUM(B21:F25*B13:F17)}		
40	Net Aggregate Welfare (zollars)			14.524	=C38-C39		
41							

Figure 2.3 Equilibrium solution for spatial transportation model.

Starting values for T_{ij}

Solver performs best when it is initially supplied with reasonably accurate starting values for the choice variables. Starting values are particularly important when the problem is relatively large and there are many corner solutions. An effective way to generate starting values is to calculate equilibrium values for a scenario where all transportation costs are equal to zero. In this "free flow" equilibrium, there is a common price, P^*, for all five regions. To obtain an expression for P^* solve the scale inverse demand, $P_i = \hat{a}_i - \hat{b}_i Q_i^D$, for Q_i^D and inverse supply, $P_i = \hat{\alpha}_i + \beta_i \hat{Q}_i^S$, for Q_i^S. Now aggregate across all regions and set aggregate demand equal to aggregate supply to obtain $\sum_{i=1}^{n}\frac{\hat{a}_i}{\hat{b}_i} - P\sum_{i=1}^{n}\frac{1}{\hat{b}_i} = -\sum_{i=1}^{n}\frac{\hat{\alpha}_i}{\hat{\beta}_i} + P\sum_{i=1}^{n}\frac{1}{\hat{\beta}_i}$. This expression can be solved to obtain the free flow equilibrium price:

$$P^* = \frac{\sum_{i=1}^{n}\frac{\hat{a}_i}{\hat{b}_i} + \sum_{i=1}^{n}\frac{\hat{\alpha}_i}{\hat{\beta}_i}}{\sum_{i=1}^{n}\frac{1}{\hat{b}_i} + \sum_{i=1}^{n}\frac{1}{\hat{\beta}_i}} \tag{2.5}$$

Figure 2.4 shows the calculation of P^* for the case study. The array formulas in cells K4:K5 and K7:K8 are expressions for the four terms in the numerator and denominator of equation (2.5). These array formulas are linked to the intercept and slope parameters that reside in cells B5:E9 of Figure 2.3. Equation (2.5) and the four expressions in cells K4:K5 and K7:K8 are used to generate the $P^* = 0.178$ value that appears in cell K10. In cells N5:O9 this free flow equilibrium price is used in conjunction with inverse supply, $\hat{P}_i = \hat{\alpha}_i + \hat{\beta}_i Q_i^S$, and inverse demand, $Q_i^D = \hat{a}_i/\hat{b}_i - 1/\hat{b}_i\,P_i$, to generate free flow levels of supply and demand for each region. Free flow exports, which is the difference between free flow supply and demand, are reported in cells P5:P9 of Figure 2.4. The free flow equilibrium is confirmed by noting from cells N10 and O10 that supply and demand aggregated across all regions is equal to 34.788.

The values in bold font in cells N5:O9 of Figure 2.4 provide good starting values for the elements of the principle diagonal of the T_{ij} shipment matrix, which is displayed in Figure 2.5. To see how this works notice that in the free flow equilibrium Mexico will keep 1.357 *ktons* of tomatoes for itself and ship the remaining 0.988 *ktons* to the three importing regions. Similarly, Latin America will keep 5.322 *ktons* for itself and ship the remaining 1.791 *ktons* to the three importing regions. Consequently, 1.357 is a good starting value for the Mexico–Mexico cell in the shipment matrix and 5.322 is a good starting value for the L. Amer–L. Amer cell in the shipment matrix.

	I	J	K	L	M	N	O	P
2			=-B5/D5+(1/D5)*$K$10			=C5/E5-(1/E5)*$K$10		
3	Sum of intercept/slope:							
4		Supply	-26.196		Region	Supply	Demand	Export
5		Demand	49.703		Mexico	2.344	**1.357**	0.988
6	Sum of 1/slope:				U.S.	**10.331**	12.059	-1.728
7		Supply	48.184		Canada	**0.512**	0.730	-0.218
8		Demand	83.796		EU	**14.478**	15.310	-0.832
9					L. Amer.	7.113	**5.322**	1.791
10	Free Flow equil. price:		0.178		Total	34.778	34.778	
11								
12	={SUM(B5:B9/D5:D9)}		=(K5+K4)/		={SUM(1/D5:D9)}			
13	={SUM(C5:C9/E5:E9)}		(K8+K7)		={SUM(1/E5:E9)}			
14								

Figure 2.4 Solving for the free flow equilibrium prices and quantities.

	A	B	C	D	E	F	G
19	**Shipments Solution Matrix with Starting Values (ktons)**						
20		Mexico	U.S.	Canada	EU	L. Amer.	Total
21	Mexico	1.357	0.000	0.000	0.000	0.000	*1.357*
22	U.S.	0.000	10.331	0.000	0.000	0.000	*10.331*
23	Canada	0.000	0.000	0.512	0.000	0.000	*0.512*
24	EU	0.000	0.000	0.000	14.478	0.000	*14.478*
25	L. Amer.	0.000	0.000	0.000	0.000	5.322	*5.322*
26	Total	*1.357*	*10.331*	*0.512*	*14.478*	*5.322*	

Figure 2.5 Initial values for Solver choice variables.

For the three exporting regions, use the free flow production values rather than the demand values as proxies for the self-shipments. Specifically, use 10.311 for the US, 0.512 for Canada and 14.478 for the EU when inserting values on the principle diagonal of the shipment matrix. The initial values for the Solver choice variables are displayed in Figure 2.5. These starting values could be further improved by identifying how aggregate exports from Mexico and Latin America are divided between the three importing regions, but this level of fine tuning is not required to solve the problem.

Solution procedure

The solution procedure begins by transferring the initial "guess" values for the shipment variables from cells B21:F25 of Figure 2.5 to cells B21:F25 of Figure 2.3. Solver must now be instructed to improve upon the 25 values contained in cells B21:F25 of Figure 2.3 so as to maximize the net aggregate welfare expression in cell D40. Begin these Solver instructions by entering "D40" in Solver's "Set Target Cell" slot and entering B21:F25 in Solver's "By Changing Cells" slot. Note that there are no constraints in this problem other than $T_{ij} \geq 0$ because, as discussed above, the $\sum_{j=1}^{N} T_{ij} \leq Q_i^S$ and $\sum_{j=1}^{N} T_{ji} \geq Q_i^D$ constraints have been directly incorporated into the spreadsheet as equalities. The absence of constraints implies that Solver's "Subject to the Constraints" slot can remain empty. The $T_{ij} \geq 0$ constraints can be included by checking the "Assume Non-Negative" box under Solver Options (accessed from Solver's main dialogue sheet). At the same time it is useful to increase solution efficiency by checking the "Quadratic" option.

The programming model can now be solved by clicking Solver's "Solve" button. In the absence of programming errors, Solver will return a message indicating that it has found an optimal solution or that it has converged to the current set of values. If the latter message appears it is a good idea to run Solver again to ensure that the solution has fully converged. Convergence is complete when the demand and supply prices, which are contained in cells C31:C35 and E31:E35, are approximately equal within each region. Cells B21:F25 of Figure 2.3 show the final optimized T_{ij} shipment values. The equilibrium prices and quantities for each region are shown in cells B31:E35.

2.4 Case study results

The equilibrium pricing outcome for the Figure 2.3 base case is illustrated in Figure 2.6. The values in parentheses beside each region are the equilibrium prices. The solid arrows between regions identify the flow of shipments, and the dashed lines between regions indicate zero trade. The values near the lines that connect the regions are the unit transportation costs in dollars per ton.

The pricing and unit transportation cost data allow for easy verification of the LOP. For example, notice that Latin America ships to Canada, the US and the EU. In all cases, the price in the importing region is higher than the Latin American price by (approximately) the corresponding unit transportation cost. A similar relationship holds for Mexico, which exports to the US. For the regions that do not trade (e.g., Mexico and the EU), it is easy to verify in Figure 2.6 that the interregional price difference is less than the corresponding unit transportation cost.

In the base case results that are shown in Figure 2.6, why does Latin America instead of Mexico sell to Canada given that the cost of shipping to Canada is lower for Mexico? The reason is that if Mexico supplies Canada then Latin America must pick up the Mexico–US shortfall. The added cost of shipping from Latin America to the US versus Mexico to the US (142.50 – 58.50 = \$83.55/tonne) exceeds the cost savings of shipping from Mexico to Canada versus Latin America to Canada (164.43 − 96.63 = \$67.80/tonne). Notice that Canada is approximately indifferent between importing from Mexico and the US because the US price plus the unit cost of shipping between the US and Canada is approximately equal to the Mexican price plus the unit cost of shipping between Mexico and Canada.

The programming model developed in this chapter is very useful for "what if" analysis. For example, policy makers may be interested in knowing how the pattern of trade in tomatoes and the regional prices for tomatoes will change if there is a large supply reduction in the EU, possibly due to a long-term disease problem or a government policy that diverts productive capacity away from tomatoes. To analyze this issue, assume that the intercept term of the EU inverse supply schedule shifts up from $\alpha = -1.067$ to $\alpha = -0.5$. After making this change in cell B8 of Figure 2.3, the model can be resolved to generate a new set of equilibrium prices and trading patterns. The revised results are illustrated in Figure 2.3b.

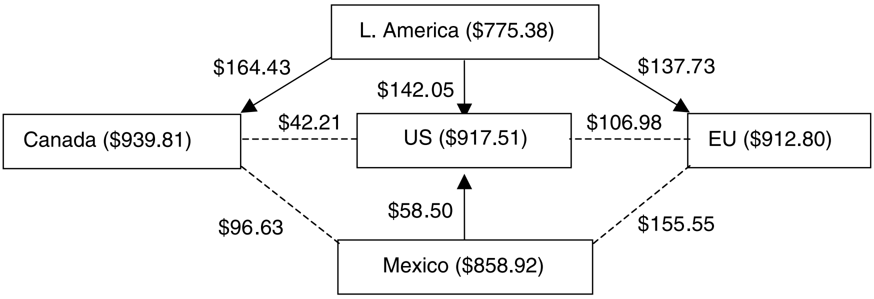

Figure 2.6 Base case results for spatial analysis of global tomato trade.

Notice in Figure 2.7 that the supply reduction in the EU has resulted in the US switching from a net importer with tomatoes flowing in from Latin America and Mexico to a net exporter with supplies tomatoes flowing out to both the EU and Canada. In the base case the EU received tomatoes from Latin America only, but now shipments arrive from Latin American, Mexico and the US. Shipments from Mexico to Canada have been replaced with shipments from the US to Canada. This "what if" scenario nicely illustrates the result that a change in production in one region can have a "domino effect" and result in a very different pattern of trade and set of prices among all trading regions.

Figure 2.7 also reveals that the supply reduction in the EU has resulted in higher importing and exporting prices for all five regions. The price differentials continue to be governed by the spatial version of the LOP, but the absolute price levels have simultaneously risen due to a reduction in production in one region. This result illustrates the extreme case of perfect pricing efficiency and market integration. In particular, with free trade consumers in commodity surplus regions are not immune to large price increases if there are large-scale supply reductions in distant regions. This issue was particularly apparent in the rice market in 2008 when several rice exporting countries imposed export embargoes to halt the rapidly escalating price of rice for domestic consumers.

A second interesting "what if" question concerns the cost of transportation. Suppose a rapid run-up in the price of energy causes a spike in the cost of transporting tomatoes. Specifically, suppose ocean freight rates doubled in value. Will the trade in tomatoes grind to a complete halt with this level of price increase? To investigate this issue, set the EU supply schedule intercept parameter back to its base level of $\alpha = -1.067$ in cell B8 of Figure 2.3, and then multiply the transportation cost parameters contained in cells B13:F17 of Figure 2.3 by two. The pricing and trading pattern results that are generated after resolving the model are illustrated in Figure 2.8. A comparison of Figure 2.6 and Figure 2.8 reveals that the trading pattern with this high transportation cost scenario is the same as the base case. This result implies that the gains from trade must be comparatively strong

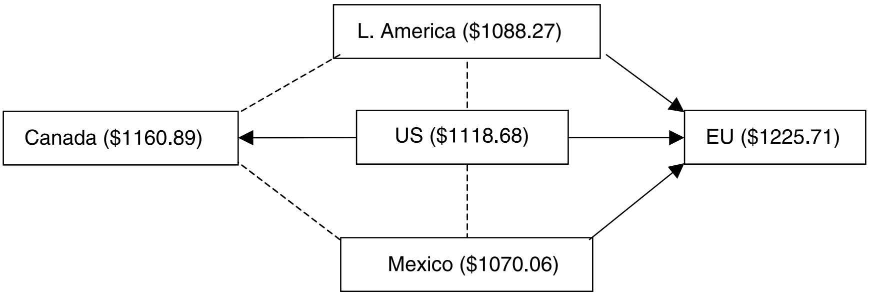

Figure 2.7 Pricing impact from a permanent supply reduction in Mexico.

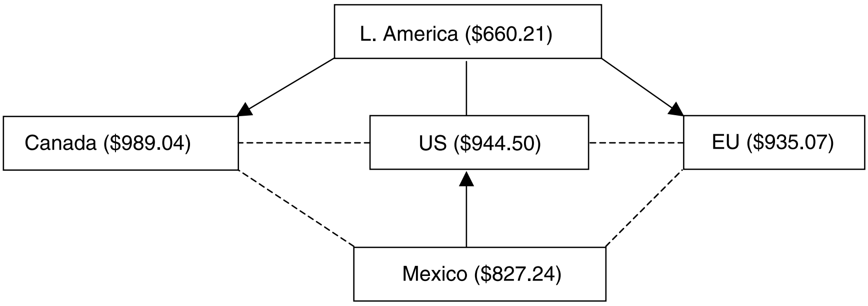

Figure 2.8 Pricing impact from a doubling in transportation costs.

because in the absence of strong gains from trade, the high cost of transportation would be expected to eliminate much of the global trade in tomatoes.

Perhaps the most interesting feature of Figure 2.8 is that the price differences between the importing and exporting regions are now very large. Indeed, the equilibrium price is approximately $990/ton in Canada and is approximately $660/ton in Latin America. The higher transportation cost drives the global trade in tomatoes toward an autarky outcome where regions with excess supply capacity face a relatively low price and regions with excess demand face a relatively high price. The high cost of transportation has significantly reduced the gains from trade.

2.5 Concluding comments

Arbitrage over space is probably the most straightforward application of the LOP to understand. Traders scan various regions for price differences that exceed the unit cost of transportation, and upon finding an arbitrage opportunity arrange for shipments from the low-price to the high-price region. Such shipments, when undertaken by a large number of traders, will continually drive up the price in the low-price region and drive down the price in the high-price region until an equilibrium is reached (i.e., until the price difference is equal to the unit cost of transportation). If the price difference is less than the unit cost of transportation, then that particular pair of regions will not trade with each other in the market equilibrium.

It is important to emphasize that shipping a commodity from one region to another for the purpose of arbitrage can be both time consuming and administratively complicated. Consequently, it is important to view the spatial LOP as a general long-run principle rather than a rule that is expected to hold in all short-run trading situations. However, despite this long-run interpretation of the LOP, the high degree of spatial price integration across markets that exists for most commodities is strong evidence that the LOP is working in both the short run and the long run. Spatial price integration should generally be viewed as a positive feature of markets because demand and supply shocks are much less severe and thus price is much less volatile when markets are well integrated.

The Excel programming procedures used in this chapter are similar to those that would be used in large-scale applications of spatial price analysis that utilize specialized software package (e.g., GAMS) to solve the model. As was hopefully demonstrated in this chapter, programming a spatial pricing problem and performing sensitivity analysis is very straightforward in Excel. Excel is therefore a good choice of software for small to medium spatial pricing problems, especially if Solver's capabilities are extended by scaling the parameters and using reasonably accurate initial values for the model's choice variables. Solver is not particularly good at solving large problems with a large number of corner solutions. It is for this reason that practitioners who frequently work with spatial pricing and similar types of linear programming problems typically choose to use specialized optimization packages rather than Excel.

Endnotes

1 Throughout this chapter the term "transportation cost" will refer to all costs associated with moving the commodity from one region to another (e.g., ocean freight, terminal storage and insurance).

2 This price quote was obtained from the Market Data Center on 15 July 2009: http://data.hgca.com/demo/archive/physical/xls/Data%20Archive%20-%20Physical%20International.xls.

3 Throughout this chapter the time required for transporting the commodity is ignored (i.e., all transactions are assumed to take place on 23 November 2005).

4 The equilibrium should be viewed as a long-run concept that is relevant for when the commodity in question is perfectly homogenous and trade deals are negotiated strictly based on price. With these assumptions transportation cost differences are the primary determinants of the equilibrium outcome and trade will generally be highly specialized. In reality, trade is not nearly so specialized because products are differentiated and non-price variables such as preferential agreements, long-term contracts and export credit packages are also important determinants of trade.

5 Examples of software which is routinely used to solve large spatial equilibrium models are GAMS and MATLAB.

6 See Huang, J. and Rozelle, S. (2006) "The emergence of agricultural commodity markets in China", *China Economic Review,* 17(3), 266–80. Their study determines that for the case of Chinese maize, price differences across a pair of regions separated by 1000 km are in the magnitude of 5 percent.

7 Shifting the import demand schedule down by an amount C_{EI} will give the same outcome.

8 In the spatial equilibrium literature the term "quasi-welfare" is often used instead of "net aggregate welfare" when referring to the aggregate area under demand minus the aggregate area under supply minus aggregate transportation costs.

9 For example, scaled revenue (*SR*) can be expressed as $SR = \hat{P}\hat{Q}$. Multiply through by z/k and k to obtain $zSR = \left(\frac{z}{k}\hat{P}\right)\left(k\hat{Q}\right) = PQ$. This equation shows that scaled revenue is equal to non-scaled revenue divided by z. Consequently, non-scaled revenue can be recovered by multiplying scaled revenue by z.

10 See Guajardo, R. G. and Elizondo, H. A. (2003) "North American tomato market: a spatial equilibrium perspective", *Applied Economics,* 35(3), 315–322. The USDA provides additional background information: http://www.ers.usda.gov/Briefing/Vegetables/tomatoes.htm

11 The assumption that ocean freight rates for fresh tomatoes are proportional to miles transported is generally not valid. Moreover, the assumed rate of $0.03 per ton per mile was arbitrarily specified (the $0.03 value was chosen because it gives rise to a set of equilibrium prices that look "reasonable"). The results of the simulations to follow should therefore be viewed as illustrative rather than an accurate estimate of prices in the global tomato market.

12 Cell D39 contains the array formula "={SUM(B21:F25*B13:F17)}". To enter an array formula do not include the { } but it is necessary to finalize the formula with <ctrl><shift><enter> rather than a simple <enter>.

Questions

1. Countries A and B both produce coffee and export all of it to Country C. The export price is $0.03/lb higher in A than in B. What can you conclude about the transportation costs that are associated with these three countries?
2. Countries A and B are net exporters of maize and countries C and D are net importers of maize. Assuming that the market consists of these four countries, demonstrate that only in a special case will A export to both C and D and at the same time B will export to both C and D. Assume that the transportation cost between each pair of counties has a unique value.
3. Countries A, B and C produce, consume and trade apples. Last year wholesale prices in Countries A, B and C were $0.56/kg, $0.59/kg and $0.52/kg, respectively. During that period two pairs of countries traded apples with each other (e.g., A exports to B and C). Describe two possible trading scenarios that are consistent with the spatial version of the LOP. For each scenario, what is the set of transportation costs?
4. Referring back to Question 3, suppose that for the current year supply and demand conditions are the same as in the previous year except production in Country C is significantly lower. As a result of the lower production, Country C is now importing from Country B and Country A is not trading. What can you definitely conclude about the transportation costs between these three countries?
5. The sugar demand and supply parameters for three regions (A, B and C), as well as the grid of transportation costs, are listed in Table 2.Q. Notice that A exports everything that it produces because it has no domestic consumers. Conversely, B imports everything that it consumes because it has no domestic producers.

Table 2.Q Demand, supply and unit transportation cost parameters for Question 2.5

	Demand		*Supply*			*Unit transport cost ($/tonne)*		
Country	*Intercept*	*Slope*	*Intercept*	*Slope*	*Country*	*A*	*B*	*C*
A	0	0	2	0.5	A	0	2	3
B	100	2	0	0	B	2	0	4
C	75	1	5	0.75	C	3	4	0

Region C, which both produces and consumes, may be a net importer or a net exporter, depending on the particular values assumed for the parameters.

a Solve for the LOP spatial pricing equilibrium using both methods discussed. For the first method, program Solver to choose the three prices in the three regions to ensure that the LOP pricing relationships are not violated and total exports equal total imports. For the second method, program Solver to choose the set of interregional shipments to maximize net aggregate welfare and then recover the set of equilibrium prices. When using this latter method don't allow Solver to choose any shipments for B (because B does not produce) and for A shipping to itself (because there is no domestic market in A).
b Sensitivity analysis: without using your Excel model, predict and *explain* the impact on price in the three countries from the following events.

    i The supply intercept in region A shifts up from 2 to 6 due to disease problems.
    ii The transport cost between A and C increases from 3 to 10 due to the imposition of a tariff by region C.
    iii The demand intercept in region C decreases from 75 to 40 as a result of health concerns about the commodity in region C.