A Spatial Equilibrium and Investment Analysis of Road and Rail Freight Transport in the Sydney-Melbourne Corridor

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Abstract:

Economic analysis of interstate transport corridors has two key goals; to determine the relative efficiency of modes in meeting transport tasks; and to evaluate options for investment in infrastructure to improve transport efficiency. The construction of a multiperiod, non-linear, mathematical programming model is proposed to achieve these goals simultaneously. It combines the well known spatial equilibrium model with a multiperiod investment model. Economic surplus theory is used to determine the mix of investment and transportation options that would maximise net social welfare in the model solution

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Introduction

A key element in Government's microeconomic reform agenda is reform of transport systems On 1 July 1989, the Shipping Industry Reform Authority and the Waterfront Industry Reform Authority were established. On 30 October 1990, the two airline agreement which had regulated domestic airline services since 1952 was abandoned and a new era in domestic aviation commenced

In March 1990, the Inter State Commission released its report on road use charges. Together with efforts to achieve greater uniformity in regulations this represented an important phase in the deregulation of the road transport industry. At the Special Premiers' Conference in October 1990, agreement was reached to proceed with the formation of the National Rail Freight Corporation. This attempted reform of interstate rail freight services complements the reforms of rail systems initiated by Australian National and the state rail authorities. These processes are directed at improving efficiency of resource use through the reform of transport services in Australia. The economy wide impacts are important to Australia's export competitiveness and the competitiveness of Australia's import competing industries.

Efficiency of resource use is essential for society to gain the maximum outcome possible from its limited resources Inefficient use of resources in any industry result in opportunity costs. They are the gains that could be released through reform of that industry and hence from the re-allocation of resources to more productive activities elsewhere in the economy. Hence, reform of transport services is essential to the attainment of efficiency in resource use and the maximisation of net social welfare.

The objective of this study is to analyse relative cost efficiency of transport modes in undertaking transport tasks in the Sydney–Melbourne corridor This study represents the first in a series of interstate transport studies being undertaken by the Bureau of Transport and Communications Economics. In order for governments to make the correct decisions regarding investment in transport infrastructure, it is important to know the relative efficiency of the various transport services. Such information has implications for decisions surrounding investment in transport infrastructure, and hence the scope for society to maximise net social welfare from the use of a given set of resources

For an interstate corridor such as Sydney–Melbourne, there is a wide array of transport activities, including combinations of transport modes to perform transport tasks These tasks include passenger and freight, transported by road, rail, air and sea modes The demand for transport may involve more than one mode and may be origin to destination over the whole corridor, or only part thereof.

In meeting transport demand, there are possibilities for competition and for complementarity in the supply of transport services In meeting the demand for passenger services, travellers have a range of options (private motor car, road coach, rail and air), with their choice depending on a number of factors (such as cost, income, reliability of service, time considerations and personal preference) Similarly, the demand for freight services may be met through a number of suppliers (road, rail, air and sea), with choice depending on factors such as type of freight (high value or low value, bulk or non bulk), reliability of service, timeliness of delivery, price, availability and personal preferences.

The focus of the analysis reported in this paper is on land freight While sea and air freight are important they are regarded as separate issues for the purposes of this study. There are several reasons for this. First, road and rail account for the major share of freight in the Sydney–Melbourne corridor. Second, the principal areas of competition and complementarity in the transport of freight reside with road and rail. Third, major investment decisions relevant to the improved efficiency of freight transport need to be made in this corridor for road and rail.

Economic theory

In this paper economic analysis of interstate transport corridors has two key goals: first, to determine the relative efficiency of modes in meeting transport tasks, both current and projected; and second, to evaluate options for investment in infrastructure to improve transport efficiency.

If there were no possibility of investment in transport infrastructure, the first goal could be accomplished using a simple spatial equilibrium model (see Harker 1985). There are two main sources and destinations for freight and passengers, and a simple transportation network. Several types of freight and passenger services would be included in such a model. The travel costs associated with each transport service, given the infrastructure, would be calculated. These costs are made up of components such as the operating costs of trains or vehicles, time delay costs due to congestion, costs of accidents, cost of maintenance of infrastructure, cost of the use of infrastructure, and so on. The model would indicate the transport mode choices that would maximise net social welfare.

The existence of investment possibilities complicates the analysis. Investment in transport infrastructure should reduce the costs associated with the movement of freight and passengers, and/or increase the revenue generated from the transport system in the future. The stream of net benefits that accrue from the investment must be discounted to reflect their timing. The stream of benefits are inherently risky because they depend on changes in the demand for transport services, and on potential changes in technology and institutions in the future.

Investment decisions should be made so that the social costs of transport are minimised. The potential trade-off between investment expenditure on transport infrastructure and expenditure on travel costs can be examined using the usual marginal principles embodied in microeconomic theory. If there were one simple infrastructure investment project, the trade-offs between investment and travel costs could be analysed in a cost-benefit framework using capital budgeting techniques. In the case of the Sydney–Melbourne corridor there are many potential investment projects, many of which are interrelated. Each project, and combinations of the projects, will influence transport costs, and potentially change the optimum modal choice in the spatial equilibrium context. A further complication arises from the joint nature of the production of outputs from a transport system. Either road or rail can transport many types of freight and passengers.

It is shown in this paper that the trade-off between investment and travel costs can be analysed in a non-linear mathematical programming model. The model can assist an economist to define socially optimum modes of transport of freight and passengers, socially optimum investment in transport infrastructure and the timing of such investment, and to suggest social opportunity costs of non-optimal transport modes, non-optimal investment in infrastructure, and shadow prices on effective constraints in the transport system

Spatial equilibrium

In essence, the analysis of transport options for the Sydney–Melbourne corridor approximates a two region trade problem. Optimum trade between these regions can be determined using spatial equilibrium theory. For a single commodity and two regions, the problem can be solved using graphical analysis (for a full exposition, see Bressler and King (1970), chapter 5). The following combines graphical and algebraic approaches, and culminates in a mathematical programming approach (in the Appendix), following Takayama and Judge (1971) and Martin (1981).

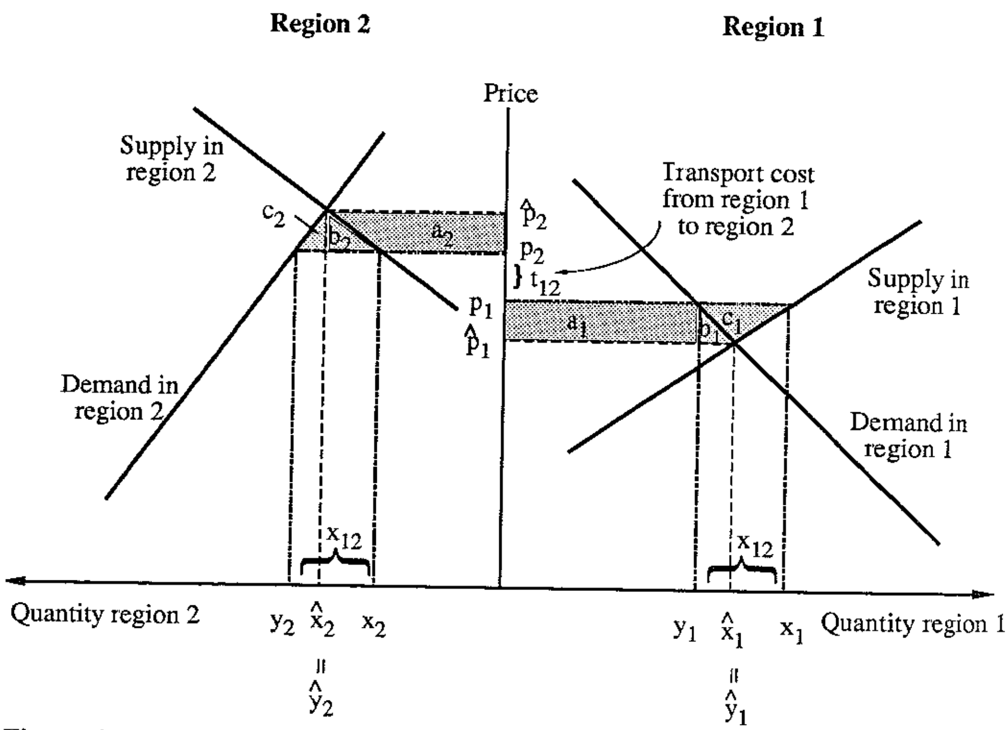

Figure 1 A two region spatial equilibrium model

In Figure 1, there are two regions with known supply and demand for a single commodity in each region. If there were no trade between the regions, the price would be $\hat{p}_1$ in region 1 and the quantity demanded, y_1 would equal the quantity supplied x_1 at the non-trade equilibrium point $\hat{y}_1 = \hat{x}_1$. In region 2 the price would be $\hat{p}_2$, with the quantities demanded and supplied being $\hat{y}_2 = \hat{x}_2$.

If transport costs between the regions is less than the difference in the prices between regions ($t_{12} < \hat{p}_2 - \hat{p}_1$), then trade would be profitable. With trade, the price in region 1 would rise to p_1 and fall in region 2 to p_2. The trade adjusted amount demanded in region 1 would be y_1 and the amount supplied would be x_1 (x_1 is composed of two quantities: x_{11} which is the amount produced in region 1, and used in region 1; and x_{12}, which is the amount produced in region 1, and transported to region 2). The difference between the quantity supplied, x_1 at the new (trade) price of p_1 exceeds the amount that purchasers in region 1 would be prepared to buy (y_1) and this quantity $x_1 - y_1 = x_{12}$ would be transported to region 2. Consider the situation in region 2; y_2 would be demanded and x_2 supplied. Thus the quantity $y_2 - x_2 = x_{12}$ would be transported from region 1. There is an equilibrium in both regions

The price equilibrium after trade is

$$p_2 - p_1 - t_{12} \leq 0$$

The quantity equilibrium is

$y_1 = x_{11}$	demand in region 1
$y_2 = x_{12} + x_{22}$	demand in region 2
$x_1 = x_{11} + x_{12}$	supply in region 1
$x_2 = x_{22}$	supply in region 2

Samuelson (1952) used economic surplus theory to define a net social welfare objective function that is maximised in determining the level of trade between two (or more) regions. When trade is allowed in Figure 1, producers in region 1 gain $a_1 + b_1 + c_1$ in producer surplus, but consumers lose $a_1 + b_1$ in consumer surplus, so that region 1 shows a net gain of c_1. In region 2 consumers gain $a_2 + b_2 + c_2$ in consumer surplus, and producers lose a_2 in producer surplus, to give a net gain of $b_2 + c_2$. Thus the net gain from trade is $c_1 + b_2 + c_2$. Samuelson showed that this gain is equal to the sum of producer and consumer surplus in the two regions. If the excess demand function is denoted as (ED), and transport costs by t_{12}, the net social welfare function is

$$NSW = \int_0^{x_{12}} (ED)dx_{12} - t_{12}$$

This is the area under the excess demand function, minus the area under the excess supply function both taken from zero to the optimum level of trade. Takayama and Judge (1964) produced a new paradigm when they showed that the spatial equilibrium problem could be solved using quadratic programming. This allowed multi-commodity, multi-regional 'real world' problems to be solved.

The matrix algebra formulation of the problem is presented in the Appendix.

Spatial equilibrium applied to the Sydney–Melbourne corridor

As indicated above, the information normally required to solve a spatial equilibrium problem are the supply and demand functions, for each commodity, in each region, the transport costs between the regions, and the set of arbitrage conditions. In the corridor problem there are two main regions (and several 'intermediate regions'), many commodities (and passenger types), reasonably well known transport costs (by mode), and simple arbitrage conditions.

The supply and demand functions for the commodities are not known. However, it is possible to determine the demand for transport services for commodities. It is a derived demand for an input to the final commodity (Friedlaender and Spady 1980). Take as an example, containers of freight in Melbourne that are destined for Sydney There is no demand for these containers of freight in Melbourne, thus the demand for this transport service in the Melbourne 'region' is zero. There is a demand for the containers in the Sydney 'region'. These demand functions can be estimated using econometric methods from historical transport flows. In a similar way, the demand functions for transport services for the various freight and passenger types can be estimated.

The supply of transport services can be derived from the costs of providing those services. A considerable amount of research has been conducted into deriving cost curves for various forms of transport (see Winston 1985), and one of the major tasks of the work proposed here is to estimate cost functions for road and rail transport for various types of freight and for passengers

Investment in infrastructure

Investment involves expenditure of funds on a 'project', with the expectation that funds will be generated by the project at some time in the future. Both the expenditure, and the income generated can be at one point in time, or spread over some time period. There are five key problems in evaluating any investment project The first is estimating the costs of the project, and the income or economic benefits that flow from the project This problem is compounded by the possible existence of a wide range of externalities. Many of the externalities are difficult to quantify The second is choosing an 'appropriate' discount rate. This is controversial, with some economists opting for a pure rate of time preference, and others for an opportunity cost of capital. A third problem is in the evaluation of the riskiness of a project based on the probability distributions of the net cash flows associated with the project A fourth problem concerns the rationing of capital among competing projects, and a fifth problem is in evaluating interdependent projects. All of these problems are considered in finance texts such as Van Horne, Nicol and Wright (1981)

The investment projects considered in the Sydney–Melbourne corridor are, for the most part, government investments. Social benefits and opportunity costs need to be considered in these investment decisions. Thus cost benefit analysis is used to assemble information regarding investment projects. As is well known, cost benefit analysis attempts to provide insight into issues such as the economic worth of public investment projects, or the determination of priorities of a range of investment projects competing for scarce capital.

Investment in transport infrastructure adds 'capacity' to a part of the transport system. The general result of the increased capacity is to lower the operating costs and or the congestion costs of transporting freight or passengers through that part of the transport system changed by the project (Small, Winston and Evans 1989, chapter 2) This has the effect of increasing consumer surplus from a to a + b in Figure 2, which is adapted from Mishan (1988 p. 20) Note that if demand had been D' there would be no change in consumer surplus as a result of increasing the capacity of the road. If demand were D', investment in increased capacity clearly could not be justified. Thus the issue to be addressed in cost benefit terms is whether the discounted benefits of increasing capacity exceed the discounted costs.

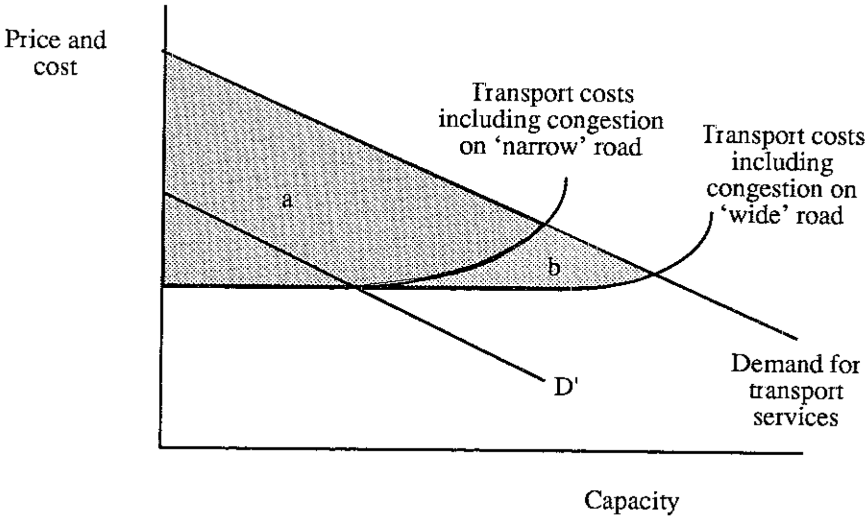

Figure 2 The effect of congestion on transport costs

Investment may also add durability to transport infrastructure (Winston 1991), and this aspect needs to be considered in a cost benefit analysis. Reliability of transport services is also important. Reliability is often seen as a key factor in determining modal choice by users of transport services. Unreliability can be costly to users of transport. These costs may encourage modal shift and result in an increase in market share by one mode at the expense of another mode. Hence, some investments may not add directly to capacity or durability of a mode, but may contribute to increased reliability. Investment then would reduce the opportunity costs associated with declining market share.

In the case of the Sydney–Melbourne corridor there are many possible investment projects, they compete for scarce capital, and many of these projects are interrelated. Rail investments provide a good example of the interrelationship between investments. If the freight terminals at each end of the rail corridor were improved, a small reduction in operating costs would occur. Operating costs could be reduced more significantly if longer trains were run, but this would depend on investment in locomotives and wagons, and in longer passing loops to accommodate the longer trains

Reasonably good estimates of the costs of the various road and rail infrastructure investments in the Sydney–Melbourne corridor are available (see, for example, The Minister for Land Transport 1991, Australian Railway Research and Development Organisation 1981, Bureau of Transport Economics 1975, and Value Management Group 1988). The major practical problem in analysing these investments is in quantifying the benefits that accrue from each investment project, and from combinations of projects. The benefits may be in the form of reduced operating costs, and or increased revenue. It is clear that to date little attempt has been made to conduct cost benefit analyses on the various rail projects that have been suggested for the corridor. Attempts are being made in the study to execute small scale cost benefit analyses on the proposals, so that they can be included in the mathematical programming model.

Research methods

Several research methods are being used in this study including econometrics, budgeting, engineering models and mathematical programming. The approach centres on the construction of a multiperiod non-linear mathematical programming model of the transport and investment options in the Sydney–Melbourne corridor. Mathematical programming has been chosen for a number of reasons

- (i) the spatial equilibrium transport problem for freight and passengers, and the problem of investment in transport infrastructure can be solved simultaneously in a single model
- (ii) the joint output nature of transport alternatives can be modelled relatively simply
- (iii) the solutions to mathematical programming models satisfy the marginal conditions of economic optima
- (iv) the models are easy to build and solve
- (v) the non–linear relationships that are important in this study can be modelled
- (vi) it can handle the discrete nature of the potential investment projects via integer programming.

The multiperiod models are used to examine the consequences of growth in demand for infrastructure requirements, over time. The investment projects for road, are the construction of four lane roads to replace two lane roads, the construction of by-passes around townships, and duplication of the Sheehan bridge. For rail the projects include terminal siding extensions and investment in loading and unloading equipment; upgrading of the track including track alignment, increasing height clearances, increasing the load and speed capacity of the track, and extending crossing loops.

There are two reasons for constructing non-linear programming models. First, some of the cost functions associated with the transport activities are non-linear. As an example, as traffic density increases on two lane roads, road damage, accident and time delay costs increase in a non-linear fashion, as illustrated in Figure 2. Second, the non-linear models are essential in solving the spatial equilibrium problem.

Attempts are being made in this study to estimate demand for various freight and passenger services, rather than the supply and demand functions for the commodities themselves. These estimates will also be used to assist in making projections of the growth in demand. In addition, simple projections of demand will be made using 'scenarios' based on economic growth assumptions. If the estimation of demand functions proves infeasible with the time and data available, and if the currently available estimates of demand are regarded as unsuitable for use in the model, the model will be adapted to minimise the social cost of transporting given quantities of the commodities. The implicit assumption in this case is that the demand for transport services is perfectly inelastic, which is an unsafe assumption in terms of economic theory.

If demand functions were not to be included in the mathematical programming model, it would become a non-linear model with the objective function of minimising net social cost, instead of maximising net social welfare, but its structure is virtually the same as the net social welfare model.

Several other research methods provide inputs to the mathematical programming model. Budgeting and engineering methods are being used to synthetically derive transport cost functions. They are being supplemented by econometric techniques to derive cost functions from data collected from transport companies, railways and the like

Outline of the mathematical programming model

Tables 1 to 3 illustrate major features of the model being used to analyse the transport and investment options. The transportation section of the model is conceptually simple, and a small section of it is illustrated in Table 1. In the table, a cost minimising objective function is assumed, and given quantities of two types of freight must be transported by either road or rail. The costs of transporting each type of freight must be calculated from cost function data derived by budgeting and econometric methods. In the actual model, many freight and passenger types, and many segments of the road and rail systems are represented.

Table 1 A Simple Transportation Model

	Transport freight type 1 by road	Transport freight type 2 by road	Transport freight type 1 by rail	Transport freight type 2 by rail	Relation-ship	RHS
Linear objective function	Calculated cost	Calculated cost	Calculated cost	Calculated cost	Minimise	
Demand for freight type 1	1		1		≥	Given quantity
Demand for freight type 2		1		1	≥	Given quantity
Road "capacity"	1	1			≤	Current capacity
Rail "capacity"			1	1	≤	Current capacity

The model is multiperiod, with a transport sub-system in each period. Investment adds capacity to a part of the transport system, and its effects continue for many periods, depending on the durability of the investment. Investment may also allow the option to reduce operating cost where physical capacity is not a constraint. The result of investment can be modelled as illustrated in Table 2. In this Table the first eight activities are the same as in the previous table, that is, they refer to the transport of freight (TF) of type (1 or 2) by mode (R–road or L–rail) and by year (1 or 2). The remaining four activities deal with investment in capacity for road (IRD) or rail (IRL) by year (1 or 2). Investment in year 1 increases capacity in year 1 and year 2, whereas investment in year 2 only increases capacity in that year. The net present value of the cost of each investment activity has to be calculated, and is included in the objective function of the model. The many periods modelled, and the many investment projects considered make the actual model quite large.

In Table 3, the demand functions for the two freight types have been added to the model illustrated in Table 1. The model is converted from a minimisation of net social costs in the objective function to maximisation of net social welfare.

Table 2 A Transportation Model with Investment in Infrastructure

Obj	TF1 R1	TF2 R1	TF1 L1	TF2 L1	TF1 R2	TF2 R2	TF1 L2	TF2 L2	IRD C1	IRL C1	IRD C2	IRL C2	Rel	RHS
	Calc cost	Calc cost	Calc cost	Calc cost	Calc cost	Calc cost	Calc cost	Calc cost	NPV cost	NPV cost	NPV cost	NPV cost	Min	
DF11	1		1										≥	G C
DF21		1		1									≥	G C
Railc1	1	1							–a				≤	C Cap
Roadc1			1	1						–b			≤	C Cap
DF12					1		1						≥	G C
DF22						1		1					≥	G C
Railc2					1	1			–a		–a		≤	C Cap
Roadc2							1	1		–b		–b	≤	C Cap

Table 3 A Transportation Model with Demand Functions

	Demand Freight 1	Demand Freight 2	TF1R1	TF2R1	TF1L1	TF2L1	Rel	RHS
Linear objective	λ_1	λ_2	–Calc cost	–Calc cost	–Calc cost	–Calc cost	Max	
Quadratic objective	ω_1	ω_2						
DF11	–1		1		1		≥	G C
DF21		–1		1		1	≥	G C
Railc1			1	1			≤	C Cap
Roadc1					1	1	≤	C Cap

Form of the results

The final models have not yet been run, however some test models have been constructed and solved It is expected that the models will indicate the following

(i) socially optimum modes of transport of freight and passengers
(ii) socially optimum investment in road and rail infrastructure, including the timing of investment
(iii) the social opportunity costs of non-optimal transport modes, and shadow prices on effective constraints in the transport system.

Implications

With the National Rail Freight Corporation due to be established on 1 July 1991, major investment decisions need to be made to improve the efficiency of rail transportation. Similarly, reforms directed at improving the efficiency of road transport have implications for its competitiveness. These reforms may influence modal shares, and may modify decisions relevant to investment in road and rail infrastructure.

The allocation of scarce capital resources among competing investment projects necessitates consideration of three important issues. First, efficient use of capital is essential in any economy. Capital is readily transferable and hence, like other mobile resources, has a high opportunity cost if it is not applied to its best use. Transport, and other sectors, compete for resources in relatively efficient capital and labour markets.

The second issue is the allocation of capital among competing projects to improve modal efficiency. This requires a detailed cost benefit assessment of the net economic worth of undertaking such investments. While it is often relatively simple to estimate the capital requirements of an investment project, it is often more difficult to identify and estimate the benefits likely to flow from such an investment. This is especially so when the returns from the investment are expected to accrue over an extended time horizon. The estimation of benefits from factors such as the improved reliability of a transport service are particularly difficult to quantify, but these estimations must be made if rational investment decisions are to be made.

Third, it is important to allocate capital among investment projects in a manner that equates the marginal net social welfare from all projects. In this way, society will gain from an optimum allocation of capital that ensures the attainment of maximum net social welfare through the most efficient use of modes within a total transport system.

The objective in undertaking this analysis was to provide insights into the second and third issues. However analyses such as the one outlined in this paper should assist governments is making their decisions involving the allocation of capital among competing projects. Thus the first issue highlights the relevance of this research.

The type of analysis discussed in this paper may be extended in at least two ways. First, it may be extended to other modes such as sea and air. Second, the analysis may also be extended to include other interstate corridors, such as Sydney–Brisbane or Melbourne–Sydney–Brisbane.

The value of such an approach lies in its ability to simultaneously evaluate where efficiency gains may be achieved and the worth of infrastructure investment options. These are key issues for government and industry, and are central to the process of micro-economic reform.

Appendix

If the demand and supply functions for each region (with n regions) are

$$p_i = \lambda_i - \omega_i y_i$$

$$p^i = \upsilon_i + \eta_i x_i$$

where p_i, p^i are the demand and supply prices (n x 1 vectors)

y_i, x_i are demand and supply quantities (n x 1 vectors)

X_{ij} is the trade flow of commodities between regions (n x 1 vector)

λ_i, υ_i are the intercepts of the demand and supply functions (n x 1 vectors)

ω_i, η_i are the slope coefficients of the demand and supply functions (n x n matrices)

t_{ij} are the transport costs from region i to region j (n x n matrix)

Takayama and MacAulay (1991) have specified the standard spatial equilibrium problem as follows:

Find $(\bar{y}', \bar{x}', \bar{X}') > 0$ that maximises

$$Z = \lambda' y - \tfrac{1}{2} y'\Omega - \upsilon' x - \tfrac{1}{2} x' H x - T' X$$

subject to

$$\begin{bmatrix} -I & 0 & G_y \\ 0 & I & G_x \end{bmatrix} \begin{bmatrix} y \\ x \\ X \end{bmatrix} \geq \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

and $(y', x', X') \geq 0$

where

$$\lambda = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{bmatrix}, \qquad \upsilon = \begin{bmatrix} \upsilon_1 \\ \upsilon_2 \\ \vdots \\ \upsilon_n \end{bmatrix}, \qquad T = \begin{bmatrix} t_{11} \\ t_{12} \\ \vdots \\ t_{nn} \end{bmatrix}$$

$$\Omega = \begin{bmatrix} \omega_1 & & 0 \\ & \omega_2 & \\ & & \ddots & \\ 0 & & & \omega_n \end{bmatrix}, \qquad H = \begin{bmatrix} \eta_1 & & 0 \\ & \eta_2 & \\ & & \ddots & \\ 0 & & & \eta_n \end{bmatrix}$$

$$G_y = \begin{bmatrix} 1 & & & 1 & & & 1 & & \\ & 1 & & & 1 & & & 1 & \\ & & \ddots & & & \ddots & \cdots & & \ddots \\ & & & 1 & & & 1 & & & 1 \end{bmatrix}$$

$$G_x = \begin{bmatrix} -1 & -1 & \cdots & -1 & & & & & & \\ & & & & -1 & -1 & \cdots & -1 & & \\ & & & & & & & & \ddots & \\ & & & & & & & -1 & -1 & \cdots & -1 \end{bmatrix}$$

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, \quad X = \begin{bmatrix} x_{11} \\ x_{12} \\ \vdots \\ x_{nn} \end{bmatrix}$$

G_y and G_x are n x n^2 matrices allowing the flow of the commodity between regions.
The quadratic programming tableau for this problem is shown in Table 4.

Table 4

	y	x	X	Rel	RHS
Linear	λ	$-\upsilon$	$-T$		
Quadratic	$-\Omega/2$	$-H/2$			
Constraints	I		$-Gy$	$\leq$	0
		$-I$	$-Gx$	$\leq$	0

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