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THE OPTIMAL LEVELS OF INFRASTRUCTURE IN AN ECONOMY: AN INPUT-OUTPUT APPROACH AND THE FULL FEED-BACK RELATIONS*

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Abstract:

Attempts to guide public policy on infrastructure are hampered by two problems. First is the failure of competing economic paradigms to develop satisfactory methods of accounting for the economic impact of infrastructure. Second is the cumbersome system of classifying infrastructure categories because infrastructure is used as an umbrella term for a collection of diverse private and public systems.

This study aims at answering policy questions concerning the optimal levels of infrastructure in a framework consistent with the multidisciplinary nature of the infrastructure problem.

A seven-category infrastructure classification scheme is proposed to allow infrastructure matrices to be constructed for use as planning technologies, and the necessary capital stock variables to be defined for studying the economic impact of infrastructure.

Within the Input-Output framework, an infrastructure matrix is proposed, using the seven-category infrastructure scheme on the basis of sector of origin versus destination, to satisfy the question of how much and what kind of infrastructure is needed in an economy for optimal growth.

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Anahtar Sözcükler: Optimal altyapı seviyesi, Altyapı ve iktisadi etkileri, Kamu politikası
Keywords: Optimal infrastructure, Economic impact of infrastructure, Public policy

Özet:

**Bir Ekonomideki Optimal Altyapı Seviyesi :
Bir Girdi-Çıktı Yaklaşımı ve Genel Denge İlişkisi**

Altyapı ile ilgili kamu politikasının belirlenmesinde iki önemli problemle karşılaşılmaktadır. Birincisi iktisadi okulların altyapının ekonomik etkilerini ölçmede yetersiz kalmaları,ikincisi de altyapı teriminin genelde özel ve kamu yapılarını kapsayacak şekilde net olarak sınıflandırılmasından kaynaklanan zorluklardır.

Bu çalışma altyapının çok disiplinli yapısına uygun bir biçimde bir ekonomideki optimal alt yapı seviyelerinin neler olması gerektiği sorusuna Girdi-Çıktı yaklaşımı çerçevesinde bir çözüm getirmektedir. Girdi-Çıktı tabloları çerçevesinde sektör başlangıç ve varış noktaları bazında yedi kategorilik altyapı sınıflaması önerilmiştir. Böylece planlamada kullanılacak altyapı matrisleri ve altyapının ekonomik etkilerinin hesaplanmasında kullanılan kapital stoku değişkenleri tanımlanarak, ne kadar ve hangi altyapı kaleminin optimal bir ekonomik büyüme için gerekli olduğu sorusu çözümlenmektedir.

1. Introduction:

The present work consists of two sections. The first one in particular deals with the subject of infrastructure planning from a resource allocation point of view in order to emphasize the link between economic development and infrastructure planning. Hence, it lays down the groundwork for efficient infrastructure planning by answering the question of how much and what form of infrastructure would be necessary and sufficient to maximize society's welfare function within the framework of general equilibrium analysis. The second section presents a solution to the question of the optimal levels, how much and what kind, of infrastructure needed in the economy based on the Input-Output (I-O) framework, thereby emphasizing the full-feedback relations in the process and developing an infrastructure matrix which can be obtained by adopting the proposed seven-category infrastructure scheme on the basis of sector of origin vs. destination.

2. Planning for Infrastructure

Given that feasibility studies of projects in infrastructure planning typically employ cost-benefit techniques (e.g., a choice between building a hydroelectric power plant or a thermal plant) as their choice of technology, the partial equilibrium nature of the cost-benefit analysis cannot capture all the gains and losses that may occur in an economy due to a change in the production of a certain good induced by planned infrastructure investment[1]. However, to achieve an optimal allocation of resources among alternative uses in an economy, efficient infrastructure planning requires that the macroeconomic effects of an induced infrastructure investment be known. Thus, efficient infrastructure planning in a decentralized decision-making environment falls under the purview of welfare economics, since, as a branch of economic theory, welfare theory deals with investigating the nature of the policy recommendations which can be made as a result of studying such effects[2].

As a resource allocation problem, welfare theory discusses the optimal distribution of products among consumers by emphasizing two theoretically well-defined concepts: Pareto optimality and Productive efficiency. The former requires that a society maximize the utility of some arbitrarily-selected individual, subject to the requirement that there be no loss in the utility of any other individual. The latter requires that a society maximize the output of any commodity using the needed quantity of certain inputs, subject to the requirement that there be no reduction in any other output and the constraints imposed by the available quantity of each input. Note that to be Pareto optimal, an allocation of resources must be efficient. Consequently, efficiency is a necessity for Pareto optimality, since the absence of Productive efficiency means that the society has taken advantage of every opportunity to benefit one person without harming others. However, the converse is not valid. An allocation of resources may be efficient and yet not Pareto optimal. To quote Baumol's[3] metaphor would be self-explanatory: "In a world of coffee drinkers it would not be Pareto optimal to produce lots of tea and no coffee, and yet that does not preclude efficiency in the production of tea!"

The preceding optimal resource allocation criteria of Pareto optimality is widely used in aggregated neoclassical general equilibrium models. For Pareto optimal allocation, aggregated models require that a society's transformation curve (production possibility frontier) be tangent to the society's welfare (utility) curve, which also requires that the marginal rate of transformation be equal to the marginal rate of substitution. These two measurable marginal pricing concepts are used as benchmark figures in nation-wide planning models as well as in cost-benefit analysis.

The objectives of politicians or decision-making bodies of government are not always a clear-cut maximization of the social welfare function cited above. Infrastructure planning is a political process which also involves the coordination of activities and planning targets of various government entities such as municipalities, states, and the Federal government in the case of the United States, and, in addition, the State Planning Organization and Ministry of Finance in Turkey. Therefore, the actual policies of the coordinated efforts will be likely to diverge from the optimal policies in a theoretical modelling sense discussed above[4]. Nonetheless, if a federal decision-making body is determined to follow a certain infrastructure policy which favors certain regions and localities, the prices and induced activities resulting from this policy are relevant data for investment decisions rather than an imaginary optimal price and activity concept.

Thus far, emphasis has been given to allocational efficiency. Here we would like to note in passing that operational efficiency (internal efficiency) is also important for the optimal utilization and maintenance of already-built infrastructures. The implications of different types of ownership for managerial incentive structures and enterprise performance are thoroughly examined in the so-called "Privatization" literature. In sum, a quotation from Vickers and Yarrow[5] may be an appropriate concluding remark.

Given the incentive problems associated with the control of publicly owned firms, it is likely that public monitoring systems are generally less effective than their private counterparts. It has been shown, however, that this in itself does not imply that, judged against social welfare criteria, the performance of public industry will be inferior, since allowance also has to be made for the effects of the shift in the objective functions of principals. Where product markets are competitive, it is more likely that the benefits of private monitoring systems (e.g., improved internal efficiency) will exceed any accompanying detriments (e.g., worsened allocative efficiency), a view that is generally confirmed by empirical studies of the comparative performance of public and private firms. In the absence of vigorous product market competition, however, the balance of advantage is less clear cut and much will depend upon the effectiveness of regulatory policy.

In accordance with what has been said above concerning efficient infrastructure planning, in what follows, we set up a general framework for determining how much and what kind of infrastructure would be necessary and sufficient to achieve the target variables of the objective function in the minds of policy decision-makers and planners.

3. General Framework of Input-Output Analysis

Unlike the case of most planning decisions, Input-Output (I-O) analysis and modelling are, in practice, not widely used for infrastructure planning. Although I-O modelling varies from regional or nation-wide scale to multiregional (interregional) or intraregional scale, for expository purposes the following only deals with the nation-wide I-O model and its analysis.

The basic scope of the I-O model is to assess the impact on an economy of changes in exogenous elements of the model of that economy. On the basis of I-O information obtained through an I-O table (provided by the BEA of the Department of Commerce in the United States and the State Planning Organization (SPO) in Turkey), assumed changes in the final demand elements (e.g., public infrastructure spending) are translated via the so-called Leontief Inverse[6] to corresponding changes that would be needed in the outputs of the industrial sectors of a national economy.

In practice, the short run versus long run assessments of the above multiplier analyses are termed "impact analysis" versus "forecasting (projecting)," respectively. The following, however, is devoted to an impact multiplier analysis in which the three most frequently used types of multipliers[7] estimate the effects of the exogenous changes on: a) the outputs of the sectors of the economy (the so-called "output multiplier"); b) income earned by households because of new outputs ("income multiplier"); and c) employment expected to be generated because of the new outputs ("employment multiplier"). In summary, depending upon the target growth which the policy decision-making body wants to achieve in a), b), or c), an infrastructure planner can make a policy recommendation of how much and what kind of infrastructure is needed. A rigorous treatment of the above types a) and b) I-O multipliers from the point of view of the infrastructure planner follows.

Table 1, excerpted from Miller and Blair (1985), exhibits the U.S. I-O transactions table for 1979, which is aggregated into eight major sectors. On the basis of the I-O table in Table 1, the following basic material balance equation is specified by reading entries in the I-O table row-wise (demand or market oriented approach).

$$X_i = \sum_{j=1}^{8} a_{ij} X_{ij} + Y_j \qquad (i = 1.....8) \qquad (1)$$

X_i = domestic availability of the gross output of industry (i),

a_{ij} = direct requirement coefficients of I-O model,

Table 1: Input-Output Transactions Table

		PRODUCERS								FINAL DEMAND			
		Agriculture	Mining	Construction	Manufacturin g	Trade	Transportatio n	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Net Exports of Goods & Services	Government Purchases of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
Value Added	Other												
	Employees	Employee Compensation								GROSS NATIONAL PRODUCT			
	Owners of Business & Capital	Profit Type Income & Compensation Allowances											
	Government	Indirect Business Taxes											

Y_i = final demand,

where: Sector 1 = Agriculture.
Sector 2 = Mining.

....
Sector 8 = Other.

Final demand consists of the following components:

$Y_i = PC_i + GI_i + NEX_i + GS_i$

where: PC_i = personal consumption expenditures,
GI_i = gross private domestic investment,
NEX_i = net exports of goods and services,
GS_i = government purchases of goods and services.

Reformulating the material balance equation (1) above, we obtain the following in matrix form:

$[X] = [I-A]^{-1} [Y]$

$$\text{Where: } [X] = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ X_8 \end{bmatrix} \quad [I-A] = \begin{bmatrix} 1 & 0 & . & 0 \\ 0 & 1 & . & 0 \\ . & . & . & . \\ 0 & . & . & 1 \end{bmatrix} - \begin{bmatrix} a_{11} & a_{12} & . & a_{18} \\ a_{21} & a_{22} & . & a_{28} \\ . & . & . & . \\ a_{81} & a_{82} & . & a_{88} \end{bmatrix} \qquad (2)$$

$$[Y] = \begin{bmatrix} PC_1 & + & GI_1 & + & NEX_1 & + & GS_1 \\ PC_2 & + & GI_2 & + & NEX_2 & + & ..... \\ ..... & & ..... & & ..... & & ..... \\ ..... & & ..... & & ..... & & ..... \\ PC_8 & + & ..... & + & ..... & + & GS_8 \end{bmatrix}$$

Equation (2) above is used as a basis for the multiplier analysis. If $[I-A]^{-1}$ in equation(2) is computed and written as

$$\begin{bmatrix} r_{11} & r_{12} & \cdots\cdots & r_{18} \\ r_{21} & r_{22} & \cdots\cdots & r_{28} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ r_{81} & r_{82} & \cdots\cdots & r_{88} \end{bmatrix}$$

naturally $\{r_{ii}\}$s, being always greater than 1[8], measure the direct impact on the gross output of a unit change in the final demand for sector (j), as all other final demands are set at zero. The other elements $\{r_{ij}\}$s measure the indirect impacts.

The term $\sum_{i=1}^{8} r_{ij}$ is therefore known as an output multiplier, type a). These output multipliers for each (j) sector can easily be calculated so that each sector is ranked with respect to the size of its multiplier. If an infrastructure planner were trying to determine in which sector (or region, in interregional models) of the economy to spend an additional dollar, a comparison of output multipliers[9] for different sectors would show where this spending would have the greatest impact in terms of the total value of output generated throughout the economy.

It may be noted that the Leontief Inverse in the above analysis is based on an open I-O model in which the household sector is treated as exogenous in the final demand. If the analysis is based on a closed I-O model in which the household sector is part of the Leontief Inverse as the ninth column and row, there is an additional induced impact which results in a larger total sum of direct and indirect effects. It may also be noted that the government spending (GS) column in the I-O table (Table 1) is assumed to be broken down into three columns:1) governmental current expenditures, 2) governmental capital expenditures exclusive of infrastructure, and 3) governmental infrastructure spending. In practice, the third column could also be broken down into various infrastructure modes for the U.S. economy. However, this type of breakdown is not available for the Turkish economy. To make the matter worse, aggregated public capital expenditures inclusive of infrastructure are given in the form of benchmark year data rather than in time series data form. The second multiplier analysis, type b) concerns the income multiplier. To facilitate the discussion, a look at the I-O table in Table 1 is useful. Table 1 displays the sectoral value added, comprising the three rows: 1) employee compensation, 2) profit type income and depreciation, and 3) indirect business taxes. Assuming that the primary input requirements of rows 1) and 2) are proportional to the gross output (X), we obtain the following linear relationship:

$$[V] = \begin{bmatrix} w_1 & w_2 & .... & w_8 \\ \pi_1 & \pi_2 & .... & \pi_8 \end{bmatrix}$$

$$\begin{bmatrix} WB_1 & WB_2 & .... & WB_8 \\ \Pi_1 & \Pi_2 & .... & \Pi_8 \end{bmatrix} = [V] \begin{bmatrix} X_1 \\ X_2 \\ .. \\ .. \\ X_8 \end{bmatrix}$$

$$\begin{bmatrix} WB_1 & WB_2 & .... & WB_8 \\ \Pi_1 & \Pi_2 & .... & \Pi_8 \end{bmatrix} = [B] \begin{bmatrix} Y_1 \\ Y_2 \\ .. \\ .. \\ Y_8 \end{bmatrix}$$

$$[B] = [V][I - A]^{-1}$$

where:

WB_i = employee compensation by sector (i),
P_i = profit type of income by sector (i).

[V] is a matrix of two primary input requirements per unit of output in our simple model, with w_1 being the labor compensation requirement per unit of gross output. The matrix [B] therefore comprises two types of income multipliers: 1) labor income multiplier and 2) non-labor income multiplier. Each element b_{ij} in matrix [B] gives the direct and indirect requirement for the (i)th primary input when the (j)th final demand changes only one unit.

The above link for final demand to the primary input is very important in establishing a causal link between public infrastructure expenditure and profits or wages. In the aggregated models,this equation is stated as one of the behavioral equations,namely as a simultaneously-determined investment model. Due to the unavailability of historical data for the coefficient matrix, instead of using a multiplicative $[V][I-A]^{-1}$ coefficient matrix in the above causal link set, we estimate this coefficient matrix by utilizing econometric techniques.

Up to this point, this work has emphasized that the practical usage of the infrastructure planning modelling presented above has only taken into account a one-way causality from the final demand side to the sectoral gross output or value added side, and has shown how the linkages between infrastructure spending and value added (specifically, the components of the value added, e.g., profits) are established. However, nothing has been said above about the full-feedback relations between the final demand and sectoral output or value added. This is at the core of integrating I-O models into macroeconometric models by endogenizing the final demand, that is endogenizing the private investment column in the I-O models. It should be noted that endogenizing private investment needs to be derived from one of the theoretical models in the literature which is also relevant to the structural and institutional features of the economy.[10]

As we have explained, the government spending column (which is displayed on the final demand side of the I-O table) can be broken down into three columns: current expenditures, capital expenditures exclusive of infrastructure, and infrastructure expenditures. In practice, however, the third column can be further broken down into various infrastructure modes. Nonetheless, this type of breakdown is not available for any economy that we are aware of.

Howewer we propose that the following seven-category infrastructure classification be used for practical purposes:

1- Roads Group: Roads, Streets, and Bridges
2- Transportation Services Group Transit, Rail, Ports, and Airports
3- Water Group: Water, Wastewater, All Water Systems Including Waterways
4- Waste Management Group: Solid-Waste Management Systems
5- Buildings, Education, and Outdoor Sports Group
6- Energy Production and Distribution Group: Electricity and Gas
7- Communications Group: Postal and Telecommunications Network Systems

Again, from the standpoint of more effective, rational, and realistic planning for infrastructure, we would argue that it is imperative that the historical (actual) infrastructure matrix be worked out. This could be done, we would suggest, by adopting the seven-category infrastructure classification scheme laid out earlier on the basis of sector of origin vs. destination.

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Notes:

[1]See Helmers (1979) for a thorough discussion of the dilemma of planners caught between objectives in project planning and nation-wide development planning.
[2]See Baumol (1977).
[3]See Baumol (1977), pp. 502-503.
[4]See Blitzer (1975), chapters 1 and 2, for more on the inconsistencies in the dialogue between model builder and planner.
[5]See Vickers and Yarrow (1988), p. 44.
[6]See Leontief (1966).
[7]See Miller and Blair (1985) and Bulmer-Thomas (1982).
[8]In some of the written work in I-O analysis, the direct impact of $\{r_{ij}\}$s above is considered as having two components: initial and direct. This is inherent in the definition of using a short-cut method for finding multipliers via the power-series approximation, namely,

$$[I-A]^{-1} = I + A + A^2 + A^3 + ...,$$

and the term "initial" is associated with (I) term, "direct" with (A), and "indirect" with the remaining terms, $A^2 + A^3 + ...$

[9]Output multipliers are also crude forms of so-called backward linkages in which the aim is to measure the potential stimulus to other activities from investment in any sector (j). In other words, the scope is to trace the output increases which occur in supplying sectors when there is a change in the sector using their outputs as inputs. On the other hand, forward linkages trace the output increases which occur or might occur in using industries (rather than supplying industries as in the backward linkages) when there is a change in the sector supplying inputs. In their crudest forms, forward linkages are measured or analyzed by looking at the sum of each row in the Leontief Inverse $[I-A]^{-1}$, as are backward linkages by the sum of each column of Leontief Inverse. For more accurate and diverse measurement of linkages, see Bulmer-Thomas (1982), pp. 190-197.

[10] See Arslan (1993) for a through discussion.