ROLE OF INFRASTRUCTURE INVESTMENT IN REGIONAL GROWTH A DYNAMIC SIMULATION APPROACH

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Abstract: This paper proposes a framework and a model for dynamic simulation to better understand the role of infrastructure in regional growth. Key components of the model include systems of regional production and factor adjustment taking spatial interaction into account. The specification is based on the tenets of regional growth theory along with some well-observed empirical phenomena. The model provides adequate space for policy experimentation. Preliminary simulation runs with arbitrary but reasonable set of parameter values and infrastructure investment policy intervention produce acceptable behaviours confirming model's structural validity.

1. INTRODUCTION

Infrastructure investment is often presented as a policy instrument to serve the goal of regional balance. But the mechanism that how infrastructure investment actually affects the lung-run regional growth pattern is not very clearly understood even in theoretical setting, let alone in practical policy setting. The policy relevance of most of the research works on infrastructure has been severely diminished mainly due to the limitation of static framework and analytical techniques. The use of static framework and analytical techniques in most of the research works on infrastructure has severely diminished their policy relevance. A static framework does not allow considering the dynamic path of adjustment while analytical technique require a tractable form of the model with oversimplified assumptions. With this backdrop, this paper, makes an attempt first to draw a rough sketch of the mechanism through which infrastructure investment influences the pattern of long-run regional growth, and then set up a multi-regional economic growth model in a dynamic framework. The model makes use of both standard theoretical tenets and well-observed empirical phenomena relevant to the infrastructure. The model will be then simulated by assigning a reasonable value to parameters and activating different infrastructure policy options. Besides, the effect of infrastructure policy is examined under different cases of regions' geographical setting and degree of scale economy. The result of the simulation that falls in expected range, validates the structural consistency of the proposed model, and thereby paves the way for detailed parameter estimation and policy experiment.

In the following section, a brief review is carried out on the theoretical foundation of infrastructure policy and past research. The next section examines the empirical issues related to infrastructure investment and regional growth in a few countries of South East Asia and Japan. This will be followed by a description of the proposed framework and detail structure of the model. Finally, result of preliminary simulation is discussed and conclusion is drawn.

2. THEORETICAL FOUNDATION

There are several different theoretical approaches which aim at explaining the mechanism of regional growth and disparity, such as neo-classical theory (Bort 1960, Richardson 1969), export-base theory (Deane 1969), cumulative causation theory (Myrdal 1957, Kaldor 1970), unbalanced growth theory (Hirschman 1958) and so on. Among these, the neo-classical and cumulative models offer two mutually conflicting hypotheses, that have direct relevance to infrastructure investment policy. The standard neo-classical growth model is built on diminishing return to factors and constant return to scale. It predicts that the trade and factor flows tend to equalise factor price, and as a result the disparity between developed and lagging regions will diminish over time. Hence, regional disparity is only a short-term phenomenon and is not worth of any sort of policy intervention.

The cumulative causation school places an emphasis on the process of agglomeration (localisation and urbanisation economy) and interprets the regional disparity as an outcome of difference in degree of agglomeration in different regions. The agglomeration phenomenon makes it possible for few leading regions to have increasing return to scale. Consequently, both capital and labour can flow in the same direction (rather than in opposite directions as predicted in the neo-classical theory). Once the growth process is set in motion, it continuously reinforces the growth in core areas at the cost of peripheral areas. Recognition of the role of increasing return in the recently evolved endogenous growth theory (Romer 1986, Krugman 1991) has given a fresh impetus to cumulative causation model.

Though conflicting in policy prescription, a combination of selected elements of these models however may provide a consistent theoretical underpinnings to set-up a framework for policy analysis. As the infrastructure policy for regional balance essentially calls for a dynamic treatment, these two models might be relevant at two different phases of economic development. As noted by North (1994), neo-classical framework is less suitable as a tool to analyse development-inducing policies. But neo-classical theory offers very elegant framework to analyse factor adjustment process in a competitive market. On the other hand, cumulative causation model might be more relevant when there is market imperfection and need for policy intervention.

The common practice in infrastructure investment related research works is first to formulate a model (usually a static one) and then to solve the model employing analytical techniques for subsequent policy evaluation. The static framework does not allow to consider the dynamic path of adjustment while analytical techniques require a tractable form of the model compelling to oversimplify the underlying mechanism with unrealistic assumptions. Besides, spatial aspect, which is a key element in regional growth, has been neglected as it adds an additional complexity to the model. As a result, the relevance and usefulness of research results for policy purpose have been severely diminished. Very little is known about role of infrastructure policy in addressing the issue of regional imbalances (Fujita and Thisse, 1996), perhaps due to such methodological constraint. It would therefore desirable to formulate a dynamic model with realistic assumptions for a meaningful policy analysis. However, it may not be possible to solve such a model through analytical techniques. In such a case numerical simulation method can be employed for solving the model and subsequent policy analysis (Naylor 1971).

3. EMPIRICAL PATTERNS

In the absence of a single integrative and well accepted theoretical framework, an investigation of empirical patterns would be an appropriate stage-setting step for formulating the policy research framework. What follows is a very broad-brush picture of ASEAN-4 countries (Indonesia, Malaysia, Philippines and Thailand) and Republic of Korea, and Japan on the trend of infrastructure investment and regional growth patterns.

3.1 Case of ASEAN-4 and Korea

The impressive economic growth in Korea and ASEAN-4 during post war period was mainly fuelled through high level of investment, but the domestic saving level was lower than the investment level. The resource gap was filled up by inflow of foreign debt and direct foreign investment (the debt-service expenditure that ranged from 30 to 60 percent of the central government current revenue in these countries during late 1980s indicates the degree of debt burden). These countries also aggressively promoted export (between 1970-1995, export rose by about 2 times in Philippines and by 3 times in Thailand by % of GDP). Manufacturing sector substantially increased it's share in export basket (Philippines accounts for 41 %, Korea 92.8 % and rest in between in 1992). Coupled with such a rising trend of manufacturing-based export is an increased emphasis on infrastructure to support export-oriented manufacturing sector. The foreign borrowing from public sources in these countries was mainly to finance capital intensive infrastructure projects. For instance, during 1979-85, Korea borrowed over 10 billion US$ from foreign public sources. Over 85 percent of this borrowing was for financing infrastructure projects (Government of Korea 1996). Yet, these countries face severe deficiency of infrastructure (World Bank 1995, 1997a). A few urban areas (mostly the capital city) account for a major share of economic output and population. The capital city, in particular, being a most competitive place for economic activities, still attracts high share of infrastructure investment.

3.2 Japan's case

Infrastructure investment has remained one of the key elements in the process of regional growth in Japan. During post war recovery period (1945-60) and first phase of high economic growth period (1960-65), high emphasis was placed on the infrastructure development, first in central Japan comprising of Tokyo, Nagoya and Osaka metropolitan region and later along the pacific belt. This approach resulted in a heavy concentration of population and economic activities in the core region. To reverse the trend, various policy measures have been taken and infrastructure investment is one of them (OECD 1996).

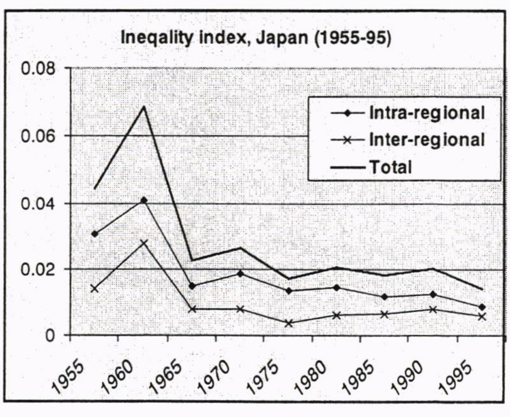


Figure1: Inequality trend in Japan

Figure 1 shows the trend of regional income inequality measured as Theil's inequality index[1] (Theil 1967). It illustrates a continuously declining trend of total inequality index since 1960. However, during 1975-90, between-the-region (inter-regional) inequality increased while within-the-region (intra-regional) inequality continued to decline. This is probably because of strong dispersion effects within the region rather than between the region.

Japan has sustained a relatively high level of infrastructure investment (8.8 percent of GDP, in 1995). However, the emphasis is now more on enhancing economic potentials of lagging regions through increased infrastructure investment. For example in 1994, Hokkaido accounted for 512 thousand yen per capita (while Kanto received only 352 thousand yen per capita) as infrastructure investment. Another striking feature is that a high share of expenditure burden is born by national government in lagging regions (62 % in Okinawa, 46 % in Hokkaido, and 39 % in Tohoku while only 30 % in Chubu and 33 % in Kanto). However, the infrastructure in lagging regions seem to be under-utilised while those in the developed regions are under pressure. For instance, the 1992 figure for ratio of gross regional product to transport infrastructure stock (road, port, and airport) in Hokkaido remained as 1.7 while that in Kanto as 4.9.

Table:1 Inter-regional output inducement coefficients

Regions	*1960*	*1970*	*1980*	*1990*
Hokkaido	1.5	1.4	1.4	1.3
Tohoku	1.4	1.3	1.4	1.5
Kanto	3.8	3.7	3.7	3.9
Chubu	2.1	2.1	2.1	1.9
Kinki	3.1	2.7	2.5	2.4
Chugoku	1.6	1.7	1.8	1.5
Shikoku	1.4	1.2	1.3	1.2
Kyushu	2.0	1.5	1.7	1.6
Okinawa			1.2	1.2

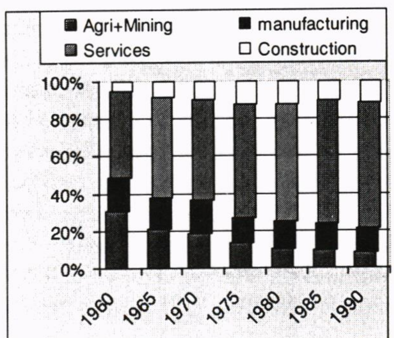


Figure 2: Value added in Hokkaido

In the process of economic development, the developed and lagging regions have followed two distinct patterns of structural change. The developed regions first witnessed rapid growth of manufacturing sector and in the later stage a shift to service sector. While lagging regions had a direct shift to service sector (with significantly high share of construction) from primary sector without passing through the phase of dominant

[1] Theil's inequality index:

Intra-regional, $I_0 = \sum_{i \in s_g} \lambda_i \log \frac{\lambda_i}{\mu_i}$

Inter-regional, $I_g = \sum_{g=1}^{G} Y_g \log \frac{Y_g}{X_g}$

Total inequality, $I = I_0 + \sum_{g=1}^{G} Y_g I_g$

y_i = share of i^{th} prefecture in total national income
x_i = share of i^{th} prefecture in national population
λ_i = share of i^{th} prefecture in the regional income
μ_i = share of i^{th} prefecture in the regional population
Y_g = share of g^{th} region in national income
X_g = share of g^{th} region in national population
G = number of regions
s_g = number of prefectures in g^{th} region

manufacturing sector. Figure 2 shows such trend in Hokkaido. The substantial share of construction is possibly due to emphasis on infrastructure investment in lagging regions. Table 1 further illustrates the trend of relative economic strength of regions measured in terms of inter-regional inducement coefficient[2] (which basically reflects the relative competitiveness of regions in terms of inter-regional trade flow). Lagging regions (except Tohoku) show a declining trends while Kanto, despite having high coefficient value, shows rising trend.

3.3. Policy Implications

The empirical patterns as observed in the above cases are too broad for any conclusive policy implication. They however provide a basis to trace out a generic role of infrastructure investment, particularly in determining the long-run patterns of regional growth. In ASEAN-4 and Korea, the investment-led growth process has created huge demand for infrastructure on one hand, and made the economy rely on foreign resources on the other. Countries have to aggressively promote export to maintain balance-of-payment stability and credit-worthiness and also enhance their competitiveness. The policy response to react such pressure is to concentrate economic activities (and investment for supporting infrastructure) in a few relatively well developed cities (mostly capital city) in order to exploit agglomeration benefits and maintain competitiveness. Such a demand-driven approach has left no room for long-run objective of regional balance. Rather this has created a positive feedback mechanism in the growth of capital cities which are experiencing high concentration of economic activities and population.

Japan's case also shows similar trend of high concentration in few cities in the core region, promoted basically through early investment in infrastructure. However, in the later stage, much emphasis was placed on increased infrastructure investment in the lagging regions with a hope to revive the economic potential of lagging regions. But, the concentration, particularly in Tokyo region, is still increasing. Overall, the regional income disparity index is declining as shown in Figure 1. This alone, however, may not be a sufficient ground to infer that regions are converging in terms of economic potential and productivity as the trend followed by interregional out-put inducement coefficients indicates regional divergence (as depicted in Table 1).

A common thread in both of the above cases is the role of infrastructure investment in influencing productivity of a region by enhancing agglomeration. If a region receives an early investment in infrastructure, it might sustain its initial advantage over other regions through reinforcing mechanism of agglomeration. This calls for a long-run perspective in designing infrastructure investment policy to ensure a balanced spatial development.

4. A FRAMEWORK FOR POLICY RESEARCH

Based on the insights gained from the above discussion, in this section, we propose a framework for policy research on infrastructure investment and regional disparity. The overall logic of the framework is based on a notion that the infrastructure investment help to build economic potential of a region in terms of its physical capacity to support a particular level of output, and it's ability to command a particular size of market area. The

[2] Out-put multiplier in each region when final demand is increased by one unit in all regions.

regional market structure in national context is largely determined on the basis of relative position of each region with respect to such economic potential. The long-run spatial pattern is then simply a result of interactions of economic agents guided through the regional market structure. Hence, the framework has two distinct domains, first depicts how infrastructure investment induces development in regions influencing relative regional competitiveness (cumulative causation framework) and, the next, how economic agents respond to market signals and allocate the factors among the regions (neo-classical framework).

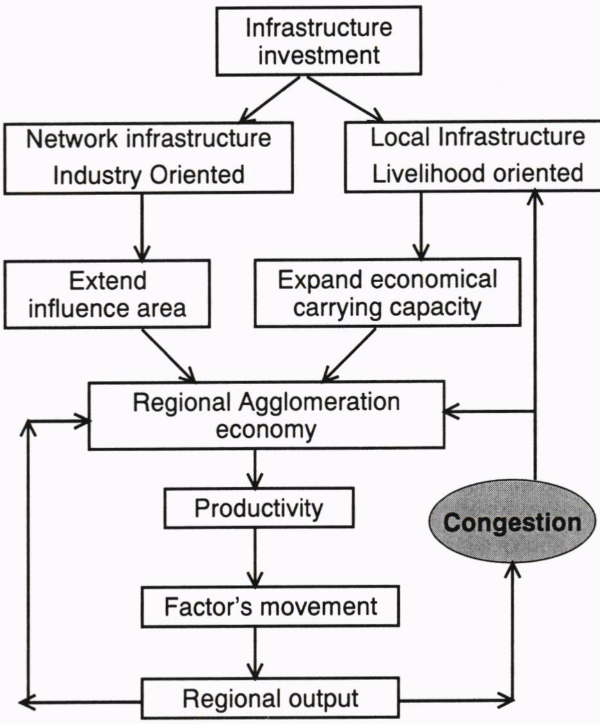


Figure 3: A framework for policy analysis on infrastructure and regional growth

Figure 3 shows an initial scaffolding of the framework. Infrastructure investment can be divided into two categories as network infrastructure (industrial development oriented) and local infrastructure (livelihood oriented). These two categories of infrastructure investment influence the regional growth process in two different ways as illustrated in the Figure 3. Here, the local infrastructure refers to those facilities whose service area is localised such as local roads and streets, water supply, sewerage and other social service infrastructures (school, hospitals, parks etc). Network infrastructure includes the national transportation networks of roads, airport and port.

The local infrastructure capital basically helps to expand the capacity of a region to support a certain level of economic production physically (or technically). To further elaborate this concept, we can imagine a space without infrastructure and the maximum possible production level the given space can support. As the amount of infrastructure capital increases, this capacity is also expanded, though the relation may not be linear. The local infrastructure, in effect, relieves the capacity constraint of a space. On the other hand, this role can also be perceived as productivity gain in the output of private factors. We can thus reasonably sum up the impact of local infrastructure as a directly contribution to the production process. However, the degree and nature of productivity impact depend upon the type of infrastructure capital. Such as local roads and streets are more production oriented local infrastructure while schools and hospitals are service oriented local infrastructure. Productivity effect of former type may be felt with a much shorter time lag while that of the later type involves considerable time lag.

The network infrastructure, on the other hand, mainly improves the accessibility of the region rather than directly improving productivity in a physical sense. That is, it influences the decision to select the place of production and, the price competitiveness of the products (part of the network infrastructure may also work as local infrastructure, such effect has not been considered here). So, the wholesome effect of network infrastructure is to enhance the competitiveness of a region through improved accessibility and subsequent extension of market area.

The production capacity and the degree of regional competitiveness jointly determine the economic potential of a region. Such potential will determine the attractiveness of the region for factor migration. Finally different regions' relative attractiveness to factors of production determines the patterns of factor movement and ultimately regions' economic production. In addition to this unidirectional causal effects, there are several feedback mechanisms involved to drive the system endogenously. For instance, when a region experiences a growth in output due to improved productivity, the expansion in output feed-backs to productivity gain. Likewise, after achieving certain output level, a region may face a congestion which retards productivity. But congestion can be relieved through additional provision of local infrastructure.

5. THE MODEL:

As explained above, the model is set in a multi-regional framework containing systems of regional production, inter-regional factor migration and spatial interaction among regions. Basic structural form of the equations have been retained as opposed to the reduced form to provide more space for policy experiment as argued by Duobinis (1981).

5.1 Regional Production:

The common supply oriented production function with Cobb-Douglas form is employed. Private capital (K), labor (L), and effective infrastructure capital (ϕ G) is used as factors of production. Here, infrastructure refers to local infrastructure (such as local roads and streets).

$$Y_i = (\phi_i G_i)^{\lambda} K_i^{\alpha} L_i^{\beta} \quad i = 1 \cdots n, \; 0 < \alpha, \beta, \lambda < 1 \qquad (1)$$

Where,

Y	regional value-added
ϕ	an infrastructure efficiency coefficient
α, β, λ	Output elasticities of K, L and G respectively
n	number of regions

It is assumed that each factors exhibits a diminishing return and G enters the production function as an unpaid factor where as K, L are paid private factors. The purpose for taking effective infrastructure capital as input is to introduce the notion of congestion (detail formulation to be explained in the later sections). Other relevant identities are,

Regional per-capita production, $y_i = \dfrac{Y_i}{L_i}$ (2)

County's gross domestic product, $Y = \sum_{i=1}^{n} Y_i$ (3)

The model has been kept unconstrained for possible cases of increasing, constant or decreasing return to scale (in K, L and G). When G is considered as an unpaid factor and production function exhibits constant return to scale in private factors (K and L), the output can be exhaustively distributed to private inputs on the basis of marginal productivity. That means, in a competitive situation, return to public capital is imputed to the returns to private capital (Negishi 1973). The scale economy in this case is however considered not only with respect to private factors but also public infrastructure (G). According to Euler's rule, under increasing or decreasing return to scale, the output will not be enough to compensate or be exhausted if paid on the basis of marginal factor return. It is therefore assumed that private factors receive their share in the proportion of their respective output elasticity. That is,

Wage rate, $w_i = \left(\dfrac{\beta}{\alpha + \beta}\right)\dfrac{Y_i}{L_i}$ (4)

Capital rent, $r_i = \left(\dfrac{\alpha}{\alpha + \beta}\right)\dfrac{Y_i}{K_i}$ (5)

5.2 Spatial interaction

An element of spatial interaction among the regions has been added to the model through the concept of economic potential (or income potential) of gravity model tradition (Isard, et al 1960, Peaker 1971, Richardson 1974). Economic potential (E) of a region is formulated as,

$$E_i = \frac{Y_i}{T_i} + \sum_{j=1}^{n-1} \frac{Y_j}{T_{ij}^{\psi}} \quad i \neq j \tag{6}$$

T_{ij} Inter-regional transport cost between regions i and j
T_i Intra-regional transport cost in region i

The transport cost is simply a multiplication of the corresponding distance and unit transport cost. Here the term 'cost' has been used in broader sense and includes value of both money and time. The unit transport cost is therefore some function of network transport infrastructure capitals over the corresponding regions to be crossed. The first term of the right hand side of the above equation represent self potential of a region, and care should be taken to appropriately work out the distance variable while computing the intra-regional transport cost. Rietveld and Bruinsma (1998) following expression for the distance variable,

$$d_i = \sqrt{(S_i/\pi)}(\pi - 1)/\pi = 0.68\sqrt{(S_i/\pi)} \tag{7}$$

Where, S_i is surface area of a region i, and if unit transport cost in a region i is t_i, then,

$$T_i = d_i t_i \tag{8}$$

In case of T_{ij}, a center-to-center distance between regions i and j is taken. However, to workout the cost this distance is segmented by regions the distance d_{ij} transects. For the region i and j, radius of the regions is taken while for others intervening regions, actual distance is taken. That is,

$$T_{ij} = \sum_k R_k t_k + \sum_m d_m t_m \quad k = i, j \tag{9}$$

Where subscript m denotes the intervening regions (ie intermediate regions transected through d_{ij}), and $R_k = \sqrt{\frac{S_k}{\pi}}$ (10)

As we can see, through these formulation, the regional economic potential (E_i) of a region i depends on the geography of regions and the unit transport cost which can be influenced through the investment in network infrastructure capital such as interstate highways, railways, airport and port. The economic potential will determine the competitive strength of a region in attracting factors of production from other regions or in inter-regional trade. In this sense, the model provides an important policy lever in the form of network infrastructure to influence regional growth.

5.3 Factor growth

Private Capital: The growth of all private factors is endogenously determined in the model while growth of infrastructure capital is exogenous as decided by policy parameters. As opposed to the national level model, in the multi-regional model there is a high mobility of factors across the regions. Adjustment of capital and labor (ie interregional transfer) has been modeled in the form of closed equations, that is the net transfer at the national level is zero. In policy analysis, this kind of formulation has a special significance. This makes it possible to see the impact of factor migration not only in the single destination or originating region (which is the case in single region model with open factor migration equation) but in both region simultaneously. Particularly, it is possible to compare the gain/loss (both short term and long term) in receiving regions against the loss/gain in originating supplying regions.

In fact, there is no clearly independent regional saving and investment system. Unlike the national system, the regional system has no independent monetary and banking authority. This makes each region to get a share from national pool of saving for investment.

Total national investment, $I = sY$, *where s is national investment ratio.*

National infrastructure investment, $I_G = hI$, $0 \le h \le 1$ (11)

National private investment, $I_k = I(1-h)$ (12)

The total national level private investment (I_k) is distributed among the different regions on the basis of their relative competitive strength. It is assumed that the share of each region in I_k, depends on the relative strength of the region in respective decision variables. Here, the output level, the capital rent (reflecting immediate profitability) and regional economic potential (reflecting long term profitability) have been taken as determining variables for private investment. To put this in equation form, Regional share coefficient, $q_i' = \frac{Y_i}{Y}\left[1 + \theta_r \frac{r_i - \bar{r}}{\bar{r}} + \theta_E \frac{E_i - \bar{E}}{\bar{E}}\right]$ (13)

where $\bar{r} = \frac{\sum_{i=1}^{n} r_i}{n}$. The parameters θ_r and θ_E represents the degree of influence of rent differential and regional potential differentials (normalized with their respective average values) over the investment distribution among the region. Here, we need to put a constraints to satisfy the condition that all regional share coefficient add to unity. Therefore, instead of the q_i', the adjusted coefficient,

$q_i = \frac{q_i'}{\sum_i q_i'}$ will determine regional share of private investment. (14)

That is, regional private investment, $I_{ki} = q_i I_k$ (15)

Hence, the factor growth equation for private capital (K) can be expressed as,

$$\frac{dK_i}{dt} = I_{ki} - \delta_k K_i \qquad (16)$$

Where, δ_k is the depreciation rate for private capital.

Labor: Likewise, there is not any regional emigration authority to regulate movement of labor, and as a result, labor is free to move across the regions to maximize net welfare. As in the case of private capital, the labor migration process is also modeled by computing a national pool of 'to be moved' labor first, and then assigning a share of this pool to each region on the basis of their respective attractiveness. In effect, a labor from this pool might settled back in the origin region (intra-regional migration) or in other region (inter-regional migration). For the modeling convenience, it is assumed that each region first contributes to a national pool of 'to be moved' labor. The contribution of each region depends upon the size of regional labor stock, natural growth rate of labor and national economic growth rate. Each region then receive a share of in-migrants from this pool depending upon their attractiveness. The regional attractiveness towards in-migrants is assumed to be dependent on labor wage differential and regional economic potential.

Moving labor in region, $P_i = pL_i g_{Li} g_Y$ (17)

Pool of moving labor, $P = \sum_i P_i$ (18)

Where, p is a constant, g_{Li} and g_Y are regional labor growth rate and national GDP growth rate respectively.

Regional migration coefficient, $m_i' = \frac{L_i}{\sum_i L_i}\left[1 + \sigma_w \frac{w_i - \bar{w}}{\bar{w}} + \sigma_E \frac{E_i - \bar{E}}{\bar{E}}\right]$ (19)

The bar over the symbol represent average values. The parameters σ_w and σ_E represents the degree of influence of the wage differential and regional potential differentials (normalized with their respective average values) over the distribution of in-migrants among the regions. Here also, we need to put a constraint to satisfy the condition that all regional share coefficient add to unity. Therefore, instead of the m_i', the adjusted coefficient,

$$m_i = \frac{m_i'}{\sum_i m_i} \tag{20}$$

will determine regional share of in-migrants. This leads to,
Net regional in-migration, $M_i = m_i P - P_i$ (21)
(a negative value of M_i would indicate a net regional out-migration).

Factor growth equation for labor (L) can be now written as,

$$\frac{dL_i}{dt} = M_i + g_{Li} L_i \tag{22}$$

<u>*Infrastructure*</u>: As explained before, investment for the infrastructure capital in each region is exogenous to the model.
Regional investment in infrastructure, $I_{Gi} = b_i I_G$ (23)
Where, b_i is policy parameter for regional share of infrastructure investment. This factor can also be represented as a variable dependent on other policy criteria (such as output share or population share of the region if infrastructure investment is allocated in the proportion of regional output or regional population). The model also makes an attempt of taking the increasing cost of providing infrastructure facilities (particularly in growing region) into account. It is a common experience that as a region accumulates more factors and infrastructure facilities, the unit cost of infrastructure construction continuously increases. Thus, as a region's infrastructure grows beyond some threshold level, the investment result in a lesser amount of physical capital than before. This logic can be justified as the posterior facilities faces additional costs due to high land cost, irregular right-of-way, cost of intersection structures and so on.

Infrastructure growth rate, $\frac{dG_i}{dt} = \mu(I_{Gi} - \delta_G G_i)$ (24)

$\mu = 1$, for $G_i < \widetilde{G}$ and $0 < \mu < 1$, for $G_i \geq \widetilde{G}$.

As noted earlier, in the production function, value of infrastructure capital is adjusted by a coefficient ϕ_i. Here, infrastructure has been treated as congestable public good. However, up to a certain level, the congestion effect is insignificant (the degree of congestion will also be compensated by some positive externalities of increased intensity of use). After crossing some threshold level in use intensity (as measured by the ratio of weighted private factors and infrastructure capital), the congestion effect prevails.

Let, $\hat{G}_i = \frac{K_i^{\alpha} L_i^{\beta}}{G_i}$ (25)

$\phi_i = 1$, for $\hat{G}_i < \widehat{G}$

$$\phi_i = \left(\frac{A}{\hat{G}_i}\right)^{\rho} \text{ for } \hat{G}_i \geq \widehat{G} \tag{26}$$

A, ρ, $\widehat{G}$ are constants.

The above given equations can be solved as a recursive system of dynamic multi-regional model. As we can see, to extent possible, the equations are based on established theoretical tenets. Additionally, attempt has been made to incorporate few empirical phenomena that are important in the context of infrastructure policy decision.

6 SIMULATION

As the model is too complex to be solved by common analytical techniques, a numerical simulation method[3] is employed for policy evaluation. However, at this stage, the scope of simulation exercise is limited to examine only the structural consistency of the model. This is important, particularly in dynamic model, as the structure of the model itself might have a significant influence over the model behaviour.

Hence, a few simulation runs are carried out with an arbitrary (but reasonable) set of parameter values to gain confidence over the model structure.

Simulation is carried out for three equal regions under the different geographical settings (as shown in figure 4 and 5) and scale economy of production function (i.e. different homogeneity of production function). These two aspects were chosen as they have been often attributed for differential regional growth. After having a base run with given parameter value, infrastructure (local) investment policies are activated (net work infrastructure investment policy has not been activated at this stage, means each regions have same unit transport cost). The value assigned to each parameter is as follows:

$K_0 = 100$	$\alpha = 0.3$	$\delta_K = 0.1$	$h = 0.07$	$\sigma_w = 4$	$\mu = 1$
$L_0 = 100$	$\beta = 0.6$	$\delta_G = 0.07$	$\theta_r = 4$	$\sigma_E = 1$	$\phi = 1$
$G_0 = 20$	$\lambda = 0.1$	$s = 0.25$	$\theta_E = 1$	$g_L = 0.015$	$\psi = 1$

Where, subscript '0' indicates the initial value of the stock variables. Besides, it is assumed, for this simulation exercise, that the normal share of each region in infrastructure investment is determined by its share in national output. This normal share, however, is modified by infrastructure policy parameter during policy intervention periods.

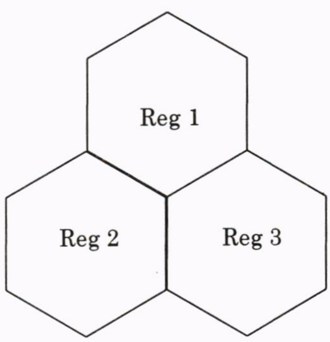


Figure 4: Triangularly situated regions

To have a better understanding of various mechanisms at work, the simulation has been carried in a step-by-step fashion. First, it is assumed that the centres of the three regions form an equilateral triangle (side of the triangle measures one unit), means regions are located triangularly (but adjacently) as shown in Figure 4. Later, another geographical setting is assumed as the three regions located adjacently in a line as shown in Figure 5. For both setting, simulation is carried out by assuming constant return to scale production technology (with the above given value of output elasticities) and increasing return to scale technology (by assuming each output elasticity 10 percent higher than the given value). Two set of infrastructure investment policy as specified below are tested:

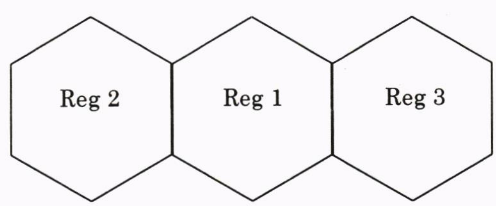


Figure 5: Linearly situated regions

[3] A System Dynamic Software (POWERSIM) has been used for this purpose.

Policy 1: The normal share of infrastructure investment in region 1 is increased by 50 percent from the year 0 to year 10 .

Policy 2: The normal share of infrastructure investment in region 1 is increased by 50 percent from the year 0 to year 10 and the normal share of infrastructure investment in region 2 and 3 is increased by 30 percent from the year 10 to year 20.

6.1 Simulation with triangularly situated regions:

Case I: *Constant return to scale:* The simulation results are shown in figure 6, chart S1.1 to S1.3. Chart S1.1 shows the base run, means simulation with given initial value and parameter values. It shows the same growth path of output per-capita for each regions. In S1.2, policy 1 is activated, which shows divergence but ultimately regions converges as predicted in neo-classical model. In S1.3, policy 2 is activated which brings the convergence earlier.

Case 2: *Increasing return to scale:* Under the increasing return to scale (in capital, labour and infrastructure), pattern of base run is same for all region (S2.1). However, under policy 1, there is sustained divergence between region 1 and the rest (S2.2). Even the increasing infrastructure investment in lagging regions do not help except a minor improvement for a short time (S2.3).

6.2 Simulation with linearly situated regions

Case I: *Constant return to scale:* Chart S3.1 of figure 6 shows the base run of this case. Here, we can see regions have a tendency of divergence even when the simulation starts with the same condition in each region and with no discriminatory policy intervention. When policy 1 is activated, the divergence is more pronounced and sustained (S3.2). Policy 2 brings some improvement but can not eliminate the divergence (S3.3).

Case 2: *Increasing return to scale:* Finally, this case shows most difficult policy situation to overcome the regional disparity. Even in the base run (S4.1), the divergence is significant. As expected, the policy 1, further fuels growth in region 1 and exacerbates regional disparity (S4.2). The policy 2 makes very little difference in growing disparity.

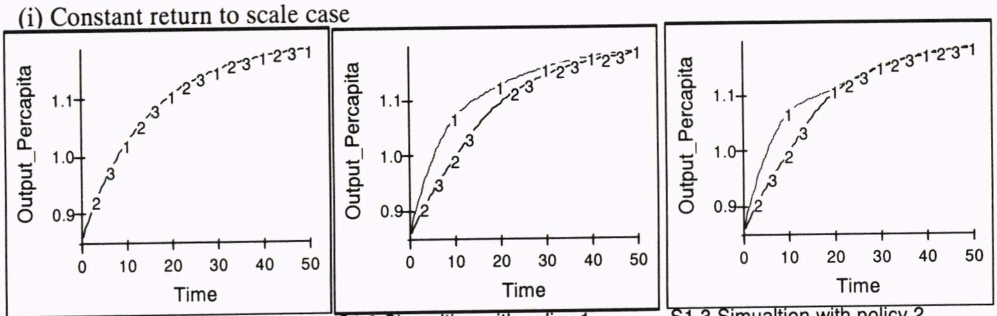
6.3 Policy implications

The simulation results discussed above provide an useful reference to derive a broad policy inference. First, effectiveness of an infrastructure investment policy depends on the geographical setting of the regions and the degree of scale economy, the economy is operating on. When the regional location is linear, the centrally located region has natural advantage over others and can easily overtake others if there is even a small policy support. Once, the centrally located regions make a gain, the reinforcing mechanism sets in motion and it could be difficult to prevent the dominance of such region. So, emphasis in infrastructure investment in the centrally located region ahead of other region, even if it justifies well, should be carefully decided keeping the future pattern of development in mind.

Likewise, we can see how the effectiveness of infrastructure investment depends upon the degree of scale economy. If there is a constant return to scale, any regional divergence

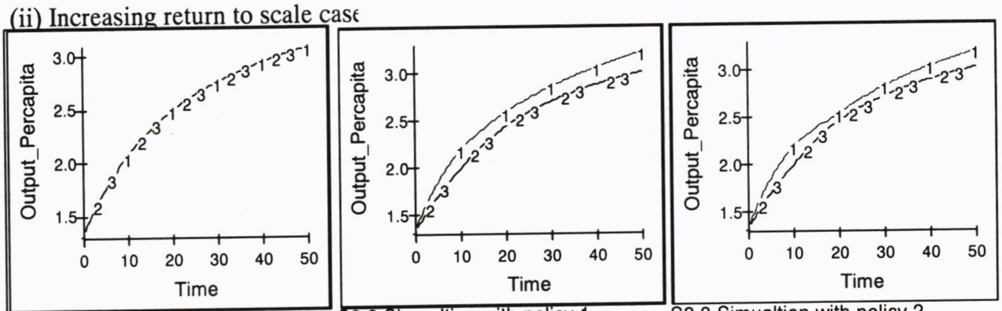
Regions situated trangularly (as in figure 4)

(i) Constant return to scale case



S1.1 Base Run S1.2 Simualtion with policy 1 S1.3 Simualtion with policy 2

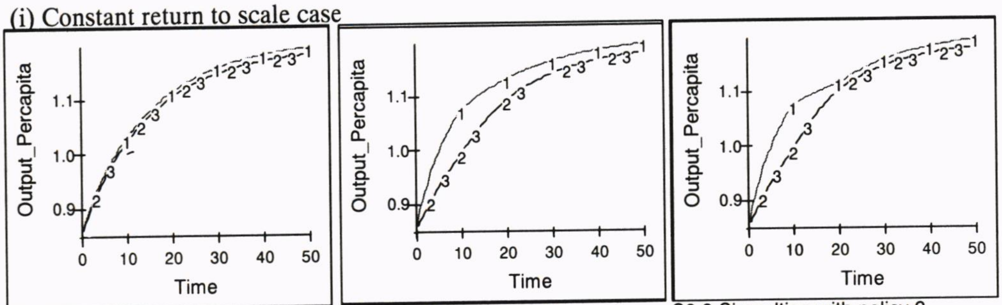
(ii) Increasing return to scale case



S2.1 Base Run S2.2 Simualtion with policy 1 S2.3 Simualtion with policy 2

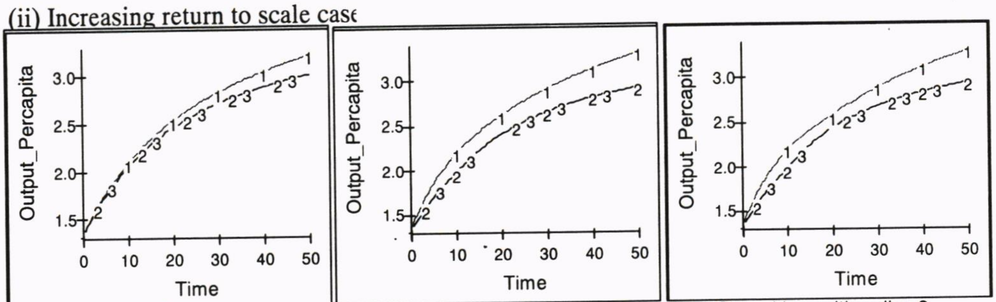
Regions situated linearly (as in figure 5)

(i) Constant return to scale case



S3.1 Base Run S3.2 Simualtion with policy 1 S3.3 Simualtion with policy 2

(ii) Increasing return to scale case



S4.1 Base Run S4.2 Simualtion run with policy 1 S4.3 Simualtion with policy 2

Figure 6: Simualtion Results with different grography, sclae effects and infrastructure policies (curve 1, 2, and 3 represents region 1, 2, and 3 respectively)

caused by discriminatory infrastructure policy can be automatically corrected over the time or can be greatly improved through infrastructure investment in lagging regions. However, the presence of high degree of scale economy not only multiplies the disparity effect of the infrastructure investment in advanced region but also makes infrastructure investment in lagging regions not very effective. The linear geography and high degree of scale economy thus constitute a vulnerable case with high possibility of diverging pattern of regional growth. Though the geography of a country remains same, the degree of scale economy does not. Particularly, at the early stage of economic growth the economy enjoy a high degree of scale economy. So, at this stage, the discriminatory investment in infrastructure may bring about a sustained regional disparity.

6 CONCLUSION AND FURTHER RESEARCH

Based on the theoretical tenets of regional science and well-observed empirical phenomena, the paper has set-up a dynamic framework for infrastructure policy analysis that led to a multi-regional model. Employing numerical simulation technique, preliminary simulation runs were carried out with reasonably assigned parameter values. The simulation results fell in the expected range of pattern and hence validated the structural consistency of the model. Besides, by comparing the results of different runs (with different infrastructure policy) a rough but important policy inference was drawn in terms of effectiveness of infrastructure policy in different geographical setting and different degree of scale economy. However, it is not yet sure if this policy inference can survive further simulation tests over the fully estimated and calibrated model.

The simulation exercise however has left few others components unexamined. The cost effectiveness of infrastructure investment and effect of congestion on infrastructure use efficiency, which had been discussed and specified in the model, have not been considered during simulation. Beside this, there may be few other extensions in the model, such as inclusion of social infrastructure capital as determinant of migration decision. Of course, most important exercise to be carried out is the estimation of parameters using empirical data. This should be followed by more extensive policy experiment.

The population sector deserves more extensive treatment at more desegregate level, such as inclusion of age groups to examine the changing pattern of age structure in different regions over time. Similarly, the mechanism representing diseconomy of over-concentration in growing also needs to be incorporated.

Note: The source of data on ASEAN-4 and Korea is World Bank (1997) and on Japan are Input-output Tables (1960-1990) and Statistical Yearbook 1998.

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