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AN APPLICATION OF INTEGRATED TRANSPORT NETWORK –MULTIREGIONAL CGE MODEL II: CALIBRATION OF NETWORK EFFECTS OF HIGHWAY

by

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An Application of Integrated Transport Network –Multiregional CGE Model II: Calibration of Network Effects of Highway

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Abstract. A transportation network-multiregional CGE model is applied to estimate the network effects of a set of highway projects on the value-added by region and industrial sector for the construction and operation periods. Among nine highways in an east–west direction in Korea, the East–West 9 highway increases the GDP by 0.300% over the 30-period time horizon with 0.016% of the GDP as the network effect. This network effect is defined as a difference between summation of the net increase in the GDP from the development of each sub-link of the highway without the spatial linkage and the change in the GDP resulting from the concurrent development of the whole links with spatial linkages. Also, the highway has the largest network effect on the manufacturing sector of Kwangju Metropolitan Area by 0.164 billion US$ per year, resulting in a gain in the regional GRP per capita by 15.88 US$ per year. Since more network effects are generated in the less-development regions such as Kwangju rather than the developed regions, highway development can contribute to the reduction in regional disparities.

JEL classification: C68, R13, R42, R58

Key words: Computable General Equilibrium model, transportation investment, network effect

1. Introduction

This paper builds on an earlier examination of the regional economic impacts of transportation investment that was centered on a significant expansion of major highway routes in Korea (Kim *et al*., 2002). However, this paper did not consider the network effects of the nearly simultaneous development of the simultaneous expansion of these routes. Network effects take place when the value of service increases more with the number of users (Koski, 1998). Schoder (2000) identified two types of network effects. The *direct network effect* results from demand side user externalities, increasing the number of users and their utility gains to operate the same system. The magnitude of the effect depends more on technical standards, the deployment of gateways, and the number of the users than on the consumption amount of the goods and services[1]. The *indirect network effect* results from supply side user externalities such as the arrangement of complementary goods and services; the functional diversification of software and hardware components (hardware-software paradigm); returns to scale such as the reduction in average production costs; technical adaptation of the production operations between supplier and demander; and administrative routine and knowledge-based adaptation (Dubois and Gadde, 2000).

In addition, Swann (2002) classified the network into three different types in terms of the relationship between the network value and the network size: broadcast network, two-way communications network, and group-forming network. In the broad network, one broadcaster provides multiple audiences with one-way directional services. It could be regarded as the least

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1 For example, the utility from the uses of fax and e-mail is positively proportional to the total number of users, and more frequent contacts among the users generate higher positive network effects (Faulhaber, 2002; Woeckener, 2000).

form of the network, and the value of the network is proportional to the size of the audience by Sarnoff 's Law. The two-way communications network includes the telephone, e-mail, and fax. The value of this network is determined by the square of the number of the users by Metcalfe's Law. Finally, the group-forming network is to form online communities, and the aggregate value depends on the number of non-trivial groups by Reed's Law.

Transportation facilities also generate network effects in a sense that the transportation network exploits economies of scope. According to Exel *et al*. (2002), the network effect of the transportation sector is defined as the distributive and generative effects that induce an increase in the economic value and a change in the spatial distribution of economic activities between regions, respectively. The investment impact of the transportation on the regional economies tends to evolve over time, so it can be disaggregated into short run effects during the construction phase and long run effects during the operation phase of the transportation project (Kim *et al*., 2002; Exel *et al*., 2002). During the construction phase, the investment stimulates final demands, but generating little effect on the economic behavior of users. During the operation phase, the supply of transportation services has a positive impact on regional economic growth by increasing the production of goods and services at a lower average production cost. In this stage, economic agents try to maximize utilities or profits by changes of industrial and residential locations, input substitution and the spatial organization of production in response to new accessibility level (see Parr *et al*., 2002).

This paper analyzes network effects of highway development on the national economic growth and the spatial distribution of income in Korea. In this paper, the network effect is defined as the difference between the incomes generated by the completion of the whole highway links and simple sum of those by each sub-link in isolation. Thus, the network effect is a net consequence from interactions among the regions across the network (Exel *et al*., 2002). This paper uses an integrated transport network model and multiregional Computable General Equilibrium (CGE) model based on Kim *et al* (2002). The transport network model measures interregional minimum distances and accessibility by highway project, while the CGE model estimates the spatial economic effects on the national and regional growth. The CGE model is developed for four industrial sectors of five Metropolitan Areas (MA), namely the Seoul MA (northwest area), the Daejon MA (central area), the Kwangju MA (southwest area), the Daegu MA (upper southeast area), and the Busan MA (lower southeast area). Each MA is composed of the largest cities with population exceeding one million and associated provinces. The model specifies the behaviors of economic agents of 20 producers, five regional households, five regional governments and a central government, and the rest of the world. The model is applied to three highway development alternatives: (1) development of the whole links of East–West 9 (EW9) highway to connect Mokpo of Kwangju MA with Busan of Busan MA; (2) development of the west-side link of EW9 highway to pass through only the Kwangju MA; and (3) development of the east-side link of EW9 highway to mainly pass through the Busan MA. In the next section, the model is presented, preceded by brief review of approaches to the measurement of network effects. Section 3 reveals the network effects of highway investment in Korea while the final section summarizes the approach and suggests future directions.

2. Model

2.1 Literature Review

The concept of a network effect has been applied to technology adoption and standardization (Chou and Shy, 1996; Gandal and Shy, 2001; Swann, 2002), competition of user network and diffusion process (Schoder, 2000; Woeckener, 2000; Dalle and Jullien, 2002), and network externalities of transportation and telecommunication (Iedaa *et al*., 2001; Wolf, 2001; see Shy, 2001 for the extensive review). Chou and Shy (1996) examined the relation between the benefit to consumers and the number of consumers purchasing the same brand. They found that the probability of the generation of positive network effects could be high for competitive computer industries and monopolistically competitive software industries because the computer firms set the price based on marginal costs. However, an individual consumer's utility might be worse off if more heterogeneous consumers purchased the same brand in a non-competitive computer market. Swann (2002) explored a functional form of the relationship between the user's utility and the size of the two-way communications network such as telephone and e-mail. The paper showed that the utility would be a linear function of the network size if a subscriber were equally likely to call any of the other subscribers in the network and the time profile of diffusion curves were identical for all users. Gandal and Shy (2001) analyzed the effect of government incentives on the formation of the standardization unions[2] with respect to conversion costs and network effects. If the network effects were small relative to conversion costs, the countries could be likely to form a union, in particular for the moderate or large conversion costs. On the contrary, if the network effects were large relative to conversion costs, the countries would not have an incentive to form the standardization union.

For network competition and technology diffusion, Schoder (2000) addressed the network effects on the adoption of telecommunication services using diffusion phenomena such as critical mass[3],

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[2] In the standardization union, the member countries mutually recognize all standards of the goods produced in other member countries.

[3] Schoder (2000) interpreted the critical mass as the turning point between positive and negative returns to adoption.

lock-in, path dependency[4], and inefficiency. The master equation approach was employed to incorporate a non-linear horizontal and vertical feedback. This paper argued that the approach with probability distributions was to precisely forecast the diffusion of telecommunication services than the linear extrapolation of trends, and that the performance of telecommunication services should be predicted based on the scenarios regarding diffusion paths. Woeckener (2000) applied a dynamic discrete choice analysis to the competition of user networks. A continuous-time master equation with state-dependent choice rates was used to determine the evolution of the probability distribution of the network sizes. It showed that the network competition could be characterized by the coexistence of lock-in regimes and a metastable state[5]. Dalle and Jullien (2002) explored the sustainability of Libre software[6] as a new economic model for software. A simple local and global interaction model was applied to the technological competition between Linux and Windows on the server operating system market. They concluded that Libre software could contribute to the promotion of efficiency due to network externalities generated by sufficient initial momentum through public intervention. Tse (2002) developed a grabber-holder dynamic framework to identify technology innovation processes, especially the winners and losers in the innovation process. The framework was composed of two dynamic technology innovation process models: a grabber value model and a holder value model. The grabber-holder model could specify whether the creative actions of the people induced the dynamic creation of the network effect in the market. This paper found that to generate and maintain the network effect depended on how the successive grabber attracted the

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[4] It was described as a competing path of development under the influence of network effects such as the field of technical standardizing, institutional regulations, and spatial economic topographies (Schoder, 2000).

[5] It is defined as a probability maximum for an arbitrary long but finite length of time (Woeckener, 2000).

[6] The Libre software could be distributed with its sources and with the right to modify and redistribute.

creative agent to provide a strong holder infrastructure. More emphasis was put on the formation of the holder rather than the successive introduction of the grabber in forecasting technological innovation.

In terms of the transportation network, Iedaa *et al.* (2001) examined determinant factors on the quality of the railway service level, focusing on the measures to stimulate the formation of an efficient transport network in Tokyo. They argued that it would be very hard to internalize the network effect and to maximize user benefits without restructuring of the organization and functional integration. Wolf (2001) examined the effects of the coexistence of different market regimes (fully liberalized intra-EU air transport and restrictive air transport markets) on the spatial distribution of international traffic flows in Germany. This paper found that the regulation of airfares and service quality induced a traffic diversion via other EU countries, and had negative spillover effects on the German air transport system.

These literatures have well documented the concept and valuation of network effects from the point of view of economic theory, but estimation of network effects through the empirical applications remains a less common feature. In general, the magnitude of the network effect relies on the competitive and complementary relationships among the various elements linked to the network, thus varying between negligible to decisive as discussed in the case of adoption and diffusion of telecommunication service by Schoder (2000). For the analysis of the network effect of transportation facilities, the approach needs to be concerned with estimation of the direct as well as indirect network effects. The direct network effect is related to the variation in the aggregated demand for the link. The indirect network effect is a spillover effect to be determined by the organization of the network, relative competitiveness of regions, and the mobility of factor inputs (Exel *et al*, 2002). Therefore the estimation of the network effect will require specification of the dynamic interactions between the transportation network and regional economic performances in a fully integrated form.

There are also issues, partially addressed in the analysis that follows, about the impact of transportation investments on regional disparities. Improvements in accessibility for regions with lower per capita incomes may yield continued advantages to existing macro regions, enabling firms located there to expand production, and the realization of scale economies and lower transportation costs penetrate markets that were formerly economically inaccessible. In the process, firms in these peripheral regions may not be able to compete as effectively. However, evidence from Japan and the US suggests that lowering of transport costs may induce an important change in the spatial organization of production (see Hewings *et al*., 1998; Parr *et al*., 2002). Firms may be able to optimize the commodity chain of production through specialization within establishments located in different parts of the country, reaping scale economies at each stage of production without incurring significant transportation costs in moving the intermediate commodity from one establishment to another.

2.2 Model Structure

The integrated transport-multiregional CGE model consists of a transport network model and a multiregional CGE model. The transport network model forecasts the travel demands between 132 transportation zones of Korea, calculating the accessibility of the highway for each transportation zone based on the minimum distances and the population size. The multiregional CGE model estimates the economy-wide impacts of the highway development on the spatial economies at a five-region division (Seoul MA, Daejon MA, Kwangju MA, Daegu MA, and Busan MA) of the country. As discussed in Kim *et al* (2002), a sizable body of literature has explored impacts of transportation infrastructure investment on economic growth using a CGE model (Buckley, 1992; Roson and Del'Agata, 1996; Roson, 1996; Kim, 1998; Rioja, 1998; Friesz *et al.*, 1998; Miyagi, 1998; Seung and Kraybill, 2001; Haddad and Hewings, 2001; Conrad and Heng, 2002; and Brocker, 2002). The framework of the multiregional CGE model in this paper is the same as the model of Kim *et al* (2002) with two differences, (1) in the regional classification and (2) in the specification of interregional trade. Kim *et al* (2002) incorporated Daegu MA (upper southeast area) and Busan MA (lower southeast area) into the Southeast Area, allowing no substitutions among the regional goods in each regional commodity market.

In the transport network model, the concept of accessibility is understood as the ease of spatial interaction or potential of contacts with activities. It can be measured in terms of potential of opportunity, physical measures, utility, inverse function of competition, joint accessibility and dynamic accessibility (Martellato *et al*, 1998). Recent European studies including Gutierrez and Urbano (1996), Linneker and Spence (1996), Rietveld and Bruinsma (1998), and Vickerman *et al.* (1999) have attempted to assess an economic benefit from the transportation projects using the economic potential approach of the accessibility variable. In this paper, the accessibility by region is derived from discounting the total number of interaction opportunities at all destination by the sum of distances with the arc and node impedances reflecting the quality of the highway network, and the regional population is regarded as a proxy variable of the level of opportunity at the destination (Martellato *et al*, 1998). Among a large number of alternatives of accessibility in Rietveld and Bruinsma (1998), the gravity type such as equation (1) has been widely applied to European accessibility studies. The parameter β in the equation is a travel distance decay parameter that results from calibrating trip distribution of 1995 with a double constrained gravity model. The shortest route algorithm in the network assignment stage results in a set of minimum travel distance, travel speeds, and travel demands on the links of the network using EMME 2 program. In the next section, the accessibility at the macro regional scale used in the CGE model is a weighted average of the levels at the transportation zone scale.

$$ACC_i = \sum_{j=1}^{n} \frac{P_j}{d_{ij}^{\beta}} \tag{1}$$

ACC_i : accessibility index for region i

P_j : population size of region j

d_{ij} : travel distance from region i to region j

The multiregional CGE model specifies the economic behavior of each producer and consumer such as production, consumption, savings and investment, government revenue and expenditure, foreign and interregional trade, and capital mobility in the real side economy. The model structure follows the neoclassical elasticity approach of Robinson (1989) to simultaneously determine prices and quantities on one hand and to limit the degree of substitution in sectoral supply and demand on the other hand. There are six economic regions, five macro regions and the rest of the world in the CGE model. In each region, production activity is divided into four industrial sectors: agriculture and mining, manufacturing, construction, and services. While economic agents are composed of producers, household, and government, each producer and household is assumed to be a price-taker, choosing an optimal set of factor inputs and commodity demand bundles under the maximization principles of constrained profit and private utility, respectively. But, the model does not impose an optimizing behavior on the government.

In the commodity market, each production sector is assumed to produce a single representative commodity, assuming constant return to scale and perfect competition. For international and interregional trade, we take into account the cross hauling attributed to heterogeneity of commodities and the aggregation problem. Thus, the commodities economic agents demand are composed of three different goods in terms of the origin of the product: intraregional supplies, regional imports, and foreign imports. The regional products are spatially distributed into intraregional supplies, regional exports, and foreign exports in terms of the destination of the product.

<<insert figure 1 here>>

The production structure consists of three-stages in the model (see figure 1). At the top of the structure, the gross output by region and sector is determined as a two-level production function of value-added and composite intermediate inputs. That is, the producer chooses quantities of the intermediate demands and the value-added using a fixed proportion of gross output following Leontief production technology. This specification allows for the substitution among labor, capital, and the accessibility reflecting the transportation services, but no substitution among the intermediate inputs and the production factors. This formulation is based on the non-sequential partial equilibrium model discussed in Kim *et al.* (2002). In general, the value-added or output is specified with two private paid factor inputs and one unpaid factor input, the infrastructure capital stock. However, the infrastructure data in monetary terms could give a misleading interpretation of the infrastructure endowment, so we use the accessibility index variable in order to take into account the potential use of the highway infrastructure (Rietveld and Bruinsma, 1998). The producer also requires an optimal set of labor and capital inputs in order to produce a given level of value-added and the accessibility using the translog production technology.

The intermediate inputs are derived from the regional input-output coefficients.

Each regional labor input is assumed to be homogeneous and intersectorally mobile, while the capital stock cannot move from one region to another during the same period. The labor demand by region and industry is derived from the producers' value-added maximization of the first order condition, while labor supply depends on the population size. Under the neoclassical closure rule for the labor market, the average wage level by region is derived from balancing out total labor demand with total labor supply that is fixed for each period. In the model, the population of the current period is a sum of natural growth of the lagged population size and the growth of net in-migrants. The in-migration is assumed to proceed in response to interregional differences in the Gross Regional Product (GRP) per capita and the population of two regions, reflecting that the potential migrants decide to move to and from the region to achieve the maximum level of expected benefit. The functional form follows Todaro (1994), and the function is estimated with time series and cross sectional data of population, wages and distances between regions from 1990 to 1995.

At the second stage, the intermediate demands are transformed into demands for the domestic product and the foreign import. We use an Armington approach to distinguish the commodity by industry and by place of origin using a small open economy assumption, specifying the imperfect substitutability between the commodities. The cost minimization with the Armington approach leads to an optimal level of the ratio of foreign imports to domestic sales. The demand for foreign imports relies on the three variables of the domestic sales, the price of domestic product relative to the domestic price of foreign import, and two key parameters of the share and the elasticity of substitution. At the final stage, the demand for the intraregional product is determined by the price and total demands for the domestic products under the Cobb-

Douglas function. On the other hand, the profit maximization with the two-level Constant Elasticity of Transformation (CET) function determines the optimal allocation of the gross output into two competing commodities, the domestic supplies and the foreign exports. The domestic supplies include both intraregional supplies and regional exports. The ratio of the foreign export to the gross output depends on the relative ratio of the price of domestic product to the domestic price of foreign export, the share parameter, and the elasticity of transformation under the revenue maximization.

The total demand for goods and services by region and industry consists of intermediate demands, total consumption expenditures of households, government consumption expenditures, and regional investment. Total household income consists of wage, capital income, and exogenous subsidy from the government, while the regional household is assumed to supply capital and labor. The total consumption expenditures are a linear function of the total household income, the direct tax rates of the regional and national governments, and the marginal propensity to save. After paying income taxes and saving, the household allocates total consumption expenditures to each commodity under the maximization of a Cobb-Douglas type utility. Household savings are linearly dependent on the household disposable income with a fixed marginal propensity to save.

Two-tiers of government structure is specified in the model: five macro regional governments and one national government. Each macro regional government is a consolidated government combining provincial (state) government and the municipalities of city and county. The expenditures of the regional and national governments are composed of consumption expenditures, subsidies to producers and households, and savings, while the common revenue source of both governments is the taxation on household incomes and value-added. In addition, the national government transfers the payments to the regional governments to make up their budget deficits, while levying tariffs on foreign imports.

In terms of the macroeconomic closure rule for the capital market, aggregate savings determine investments. There is only one capital market, and the savings consist of four main sources including household savings, corporate savings of regional production sectors, private borrowings from abroad, and government savings. There are no financial assets in the model, so overall consistency requires equating total domestic investment to net national savings plus net capital inflows. The sectoral allocation of total investment by destination is endogenously determined by the capital price by sector and the allocation coefficient of investment, and is transformed into the sectoral investment by origin through a capital coefficient matrix. The average cost pricing rule is applied to the determination of the price level that is obtained by clearing any excess demand in labor, capital, and commodity markets (Gottinger, 1998). The composite commodity price is a weighted average of the price of the domestic product and the domestic price of the foreign import. Finally, the gross output price is composed of the primary factor payment, the indirect tax rate, and the intermediate input prices (Kim and Ju, 2003).

The development of the multiregional CGE model requires a benchmark data set that should be internally consistent with the overall economic activity and fit the sectoral disaggregation of the model. A Social Accounting Matrix (SAM) is satisfied with this condition, tracking the purchases and expenditures of services and commodities. We use a revised SAM described in Kim *et al.* (2002) in which the modification has been made for the regional classification. This modified SAM consists of six accounts - factors, households, production activities, government, capital, and the rest of the world - and is treated as an initial equilibrium for the CGE model. In the multiregional CGE model, there are two kinds of parameters: structural coefficients and behavior parameters. The structural coefficients are point estimates or non-elasticity parameters derived from the short-term observation, the SAM, and cross-sectional survey data, including various tax rates and consumption propensities. The behavior parameters are the parameter derived from the historical data or long-term structural behavior of economic agents, including the elasticities of substitution and transformation in the trade and production equations (see Haddad and Hewings, 2001). All parameters are adjusted so that the model can reproduce the benchmark data of 1995, given the values for policy variables.

The CGE model is a recursive and adaptive dynamic model, and is composed of a within-period model and a between-period model. The within-period model draws heavily on the methodology described in Kim and Kim (2002) and Kim *et al.* (2002). It determines equilibrium quantities and prices under an objective and constraints for each economic agent, where the balance between supply and demand is achieved in a perfectly competitive market. The between-period model finds a sequential equilibrium path for the within-period model over the multiple periods updating values of all exogenous variables such as government consumption and investment expenditures from one period to another. For example, the current capital stock is a sum of the net capital stock at the previous period and the investment to be endogenously determined in the model. The within-period model is a square system of equation with 696 equations and 814 variables; a unique solution can be found because the number of endogenous variables is the same as the number of the equations under convexity. The exogenous variables include world market prices, population, and government expenditure, and the *numeraire* of the model is set as the price of foreign exchange in nominal terms. The numerical specification of the model is discussed in detail in Kim *et al.* (2002). In summary, the transport network model calculates an interregional minimum distance matrix and an accessibility index by highway project. The investment expenditures and the accessibility level are injected to the multiregional CGE model, which can calibrate the effects of the highway project on the spatial economic growth (see figure 2).

<< insert figure 2 here>>

3. Network Effects of Highway Investment

The transportation network-multiregional CGE model is applied to estimate the network effects of the highway project on the value-added by region and industrial sector for the construction and operation periods. The proposed national highway system of Korea may be characterized as a grid–type structure of 6,160 km consisting of seven highways in a south–north direction and nine highways in an east–west direction, all of which are expected to be completed by 2020 (Kim *et al.*, 2002). The East–West 9 (EW9) highway was selected for a counterfactual analysis of the network effect in terms of the data availability and the degree of the completion (see figure 3). The origin and destination of the highway are the city of Busan of Busan MA and the city of Mokpo of Kwangju MA, respectively. Busan is the second-largest city and one of the world's top five hub ports. Mokpo is a seaport city in the west of Korea, and has the highest population density among the cities and counties around the EW9 highway.

In estimating the network effects of the highway, EW9 highway is divided into two sub-links centering around Kwangyang in Kwangju MA where the second largest steel making company in Korea is located: one sub-link is identified between Busan and Kwangyang and another between Kwangyang and Mokpo. Thus, three highway alternatives (BK, KM, and BM) can be evaluated. On average, the cities and counties linked with the sub-link of EW9 highway between Busan and Kwangyang (alternative BK) have higher population density (1248.58 person per km^2), employment per capita (28.76%), and tax per capita (1015.59 US$) than the other case.

Alternative BK: the construction of the sub-link (Busan and Kwangyang) of eastern section of EW9 highway

Alternative KM: the construction of the sub-link (Kwangyang and Mokpo) of western section of EW9 highway

Alternative BM: the construction of the whole links (Busan and Mokpo) of EW9 highway

<< insert figure 3 here>>

As discussed in Kim *et al.* (2002), there are two kinds of the temporal effects that the transportation infrastructure generates on economic sectors.[7] One is a short run effect, the source of which is a change in the construction investment expenditure to produce a direct increase in both the growth output and price level through the expansion of aggregate demand. Another is a long run effect during which changes in the capital stock of the transportation sector and in the spatial accessibility levels combine to increase the supply level with less price inflation. The change in the accessibility depends not only the location but also the connectivity of the highway with others, and is capitalized as an increase in the value-added by region and industry through the relocation of economic activities to the place maximizing utility and profit levels (Shefer and Shefer, 1999; Banister and Berechman, 2000). These changes in the accessibility and the economic shock generate a set of new equilibrium values for regional production, population, and prices, satisfying the price normalization rule subject to the exogenous foreign exchange rate. The counterfactual simulation for a 30-year span is

[7] Due to the various reactions of the economic agents to the change in the transportation network, it is impossible to clearly define the phase in terms of years.

performed for each alternative where the construction and the operation periods are assumed to be 5 and 25 periods respectively. Since the short run effect is generated by the construction investments, the effect lasts for five periods. The long run effect comes into action from the sixth period with transforming the investment into the capital stock.

The results of each alternative are compared with the base case which is defined as a sequential path of economic behavior following an inter-temporal consistency for the periods under existing circumstances without the additional construction of the highway (Kim *et al.*, 2002). In this paper, the network effect is defined as a difference between the GDP from the alternative BM and sum of the GDP from the alternatives of BK and KM. The GDP and the construction and operation costs are measured in 1995 constant prices. The government finances construction costs though an imposition of earmarked tax on incomes of households and producers. In Table 1, Seoul MA in the base case displays the highest accessibility level (60.049) derived from the transportation network model among the five regions. Daejon MA achieves second highest level (22.227), followed by Daegu MA (18.877) and Busan MA (17.012). As shown in the table, the EW9 highway induces an increase of the accessibility for every region compared with the base case: Seoul MA by 0.015%, Daejon MA by 0.115%, Kwangju MA by 12.799%, Daegu MA by 0.235%, and Busan MA by 1.962%. In particular, the highway development can lead to higher level of accessibility for Kwangju MA (18.922), the lowest one in the base case, rather than Busan MA (17.346).

<< insert table 1 here>>

If the accessibility levels and the construction investments by region for the EW9 highway are injected into the multiregional CGE model, the GDP at 1995 constant price would increase by

129.393 billion US$ or 0.300% of the GDP over the 30-period time horizon. The sub-links of Busan-Kwangyang and Kwangyang-Mokpo also could increase the GDP by 31.847 billion US$ and 90.540 billion US$ respectively. Summing the net increase in the GDP from the development of each sub-link over the two cases without the spatial linkage, it would amount to 122.387 billion US$ in all. This value could be compared with the change in the GDP resulting from the concurrent development of the EW9 highway with spatial linkages, and the difference between them is 7.006 billion US$ (0.016% of the GDP). It can be regarded as the network effect from the connectivity of the two sub-links.

If the net increase of the annual GDP and the construction and operation costs are discounted to the present values of benefits and costs respectively,[8] the benefit-cost (BC) ratio using a discount rate of 7.5% would be 5.599 with the break-even point achieved at the end of the fifth period (see figure 4). The discounting rate reflects levels of interest rate and risk of infrastructure projects. While this benefit includes both the direct and indirect effects of the highway development on the GDP, it does not take into account the opportunity cost of other investments (Kim *et al.*, 2002). For the alternative BK, the BC ratio continues to rise from 0.094 in the starting period (the 1st year) to 3.627 in the final period (the 30th year). The construction and operation costs of this link would be paid back earlier, by the third period of the construction phase, while the growth rate of the GDP during the operation phase lower than the cases of KM and BM.

<< insert figure 4 here>>

The EW9 highway has the largest impact on the value-added of the manufacturing sector of Kwangju MA, increasing by 2.912 billion US$ on an average per year over thirty years. Since the production inputs are intersectorally allocated to maximize the profits under the neoclassical closure rule of the labor market, every industrial sector cannot generate a positive value-added. For example, the effect on value-added of the agricultural sector would decrease annually from 0.559 billion US$ to 0.102 billion US$ in all MAs except for Daegu MA. In Daegu MA, only the construction sector experiences a loss of 0.009 billion US$ per year for the 30 years. For Seoul MA and Busan MA, the service sector among the production sectors derives more benefits from the highway network development, while the manufacturing sectors are the major beneficiaries in the other three MAs.

In terms of network effects by region and industrial sector, there are substantial increases in the manufacturing sector of Busan MA and Kwangju MA, as noted for the impact on GDP. For Kwangju MA, the EW9 highway results in a gain from the network effect on the manufacturing sector of 0.164 billion US$ per year, but this is partially offset by negative network effects on the agricultural sector (-0.029 billion US$ per year) and the service sector (-0.036 billion US$ per year). For Busan MA, the annual network effect by 0.083 billion US$ in the manufacturing sector of Busan MA is generated at the cost to the decrease of network effects in the other three sectors by approximately 0.001 billion US$. Similarly, the agricultural sector generates a negative network effect in Seoul MA and Daejon MA, but none in Daegu MA.

Table 3 reports the impacts on GDP per capita. The construction of the complete links of the EW9 highway induces an increase of the GRP per capita of Kwangju MA by 338.82 US$ per year. It also raises the GRP per capita of Busan MA by 168.90 US$, Daejon MA by 53.29 US$, Daegu MA by 45.23 US$, and Seoul MA by 23.27 US$. If the network effect is measured by the GRP per capita, the EW9 highway project would have the highest network effect on the

[8] This discounting rate is what the government has used for the feasibility studies of public works.

Kwangju MA, generating an increase of the GRP per capita of 15.88 US$ per year. The second and third cases are Busan MA (11.99 US$ per year) and Daejon MA (2.73 US$ per year). In a sense that the network effect occurs in the less developed regions such as southwest (Kwangju MA) and central regions (Daejon MA) of Korea, the highway construction program would appear to contribute to decreasing regional income inequality in the long run.

<< insert table 3 here>>

An alternative approach to estimating the impact of the EW9 highway on the GRP of the sub-regional units in Kwangju MA and Busan MA, would be to use the Dendrinos-Sonis model. The Dendrinos-Sonis model was developed to assess a dynamic change of population, and recently has been applied to the analysis of economic interactions (Magalhães *et al.,* 2001; Nazara *et al.*, 2001). We follow a hierarchical structure of Dendrinos-Sonis model proposed by Nazara *et al.* (2001) in which that the income level of one region depends on the degree of the vertical interaction with the Metropolitan Areas as well as the degree of the horizontal interaction with other sub-regions[9]. Kwangju MA consists of three sub-regional units (Southwest Zone, Midwest Zone, and South Seaside Zone), and Busan MA of five sub-regional units (Mideast Urban Zone, River Inland Zone, West Urban Zone, Northwest Plateau Zone, and South Seaside Zone) according to two regional development plans. Each sub-region is again composed of a few cities and counties. Assuming that the GRP of the sub-region is jointly determined by the income tax and the population size due to the income data problem for the sub-regions, we estimate the parameters of the model with Iterative Seemingly Unrelated Regression. Since the

9 Horizontal interaction occurs among cities or provinces at the same level of hierarchical structure, and vertical interaction among different levels of the regions (nation-region) (Nazara *et al.*, 2001)).

major concern is with income changes of the regions that the EW9 highway passes through, the northern part of Kwangju MA (Junbuk province) is excluded in the figure. As presented by the following GIS map, the sub-regions in which the GRP and network effects highly concentrates on are three largest cities such as Busan, Ulsan, and Kwangju, and south coastal cities specialized in mechatronics and petrochemical industries.

<< insert figure 5 here>>

<< insert table 2 here>>

4. Summary and Further Research Directions

In this paper, the transportation network-multiregional CGE model is applied to estimate the network effects of a highway project on the value-added by region and industrial sector for the construction and operation periods. Among seven highways in a south–north direction and nine highways in an east–west direction, the East–West 9 highway increases the GDP by 0.300% over the 30-period time horizon with generating 0.016% of the GDP as the network effect. Also, the highway has the largest network effect on the manufacturing sector of Kwangju MA by 0.164 billion US$ per year, resulting in a gain in the regional GRP per capita by 15.88 US$ per year. Since more network effects are generated in the less-development regions such as Kwangju MA rather than the developed regions, the highway development can obviously contribute to a reduction in regional disparities.

As the further research directions, the extension of the model is focused on the specification of interaction between the transportation network model and the multiregional CGE model. In the current model, there is no feedback mechanism to inject the travel demand factors such as the income and the population determined by the CGE model into the transport network model. This one-way directional causality and imperfect feedback linkage are mainly attributed to different regional classification: the numbers of spatial units in the transport network model the multiregional CGE model are 132 transportation zones and five macro regions, respectively. One of the solutions to this problem would be to allocate the values of the endogenous variables of macro regions into those of micro regions, using the Dendrinos-Sonis model or spatial interaction model for each variable. Another is to extend the model into an integrated land market-transportation network-multiregional CGE model in a sense that the development of the transportation network could affect the land demand under the immobility of economic agents as well as the relocation of the factor inputs under the fixed land demand. For example, the construction of the highway has a direct effect on the land acquisition price. The operation of the highway has indirect effects on sectoral land demands and prices through the substitution of factor inputs in the long term. Also, the economic behavior of regional agents need to be specified with supply and demand of sectoral land such as industrial, residential, commercial, agricultural, and green land uses. For the production and utility functions, the industrial and commercial land uses could be the land inputs for the mining and manufacturing production and the service sectors, respectively, and the supply of residential land uses determines the household utility by region.

Finally, it is important that the findings of analyses such as these should be complemented by analysis of the changes in the structure of production – technologically and spatially – of firms within Korea. Will these transportation investments generate a hollowing out process (see Hewings *et al*., 1998) in the Seoul region to the benefit of peripheral parts of Korea as firms exploit scale economies in establishments located in different parts of the country and thereby assemble a finished product much more efficiently and cheaply than if the commodity chain of production was concentrated within the Seoul region? Analysis paralleling that for Japan (see Hitomi *et al.,* 2000) would add some important insights into the potential for such processes to be realized and thus provide even stronger motivation for continuing transportation network investment strategies.

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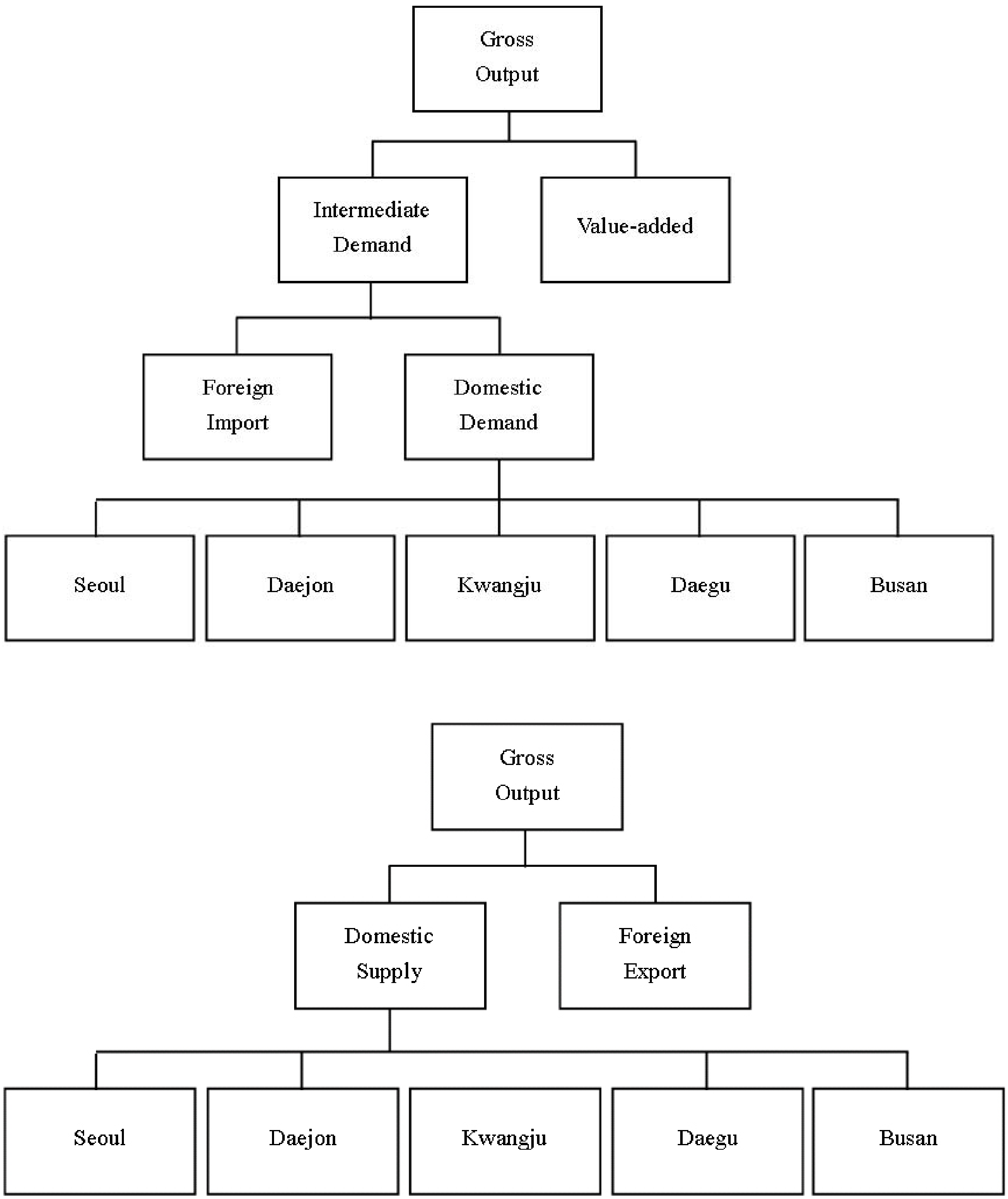

Fig. 1. Production structure

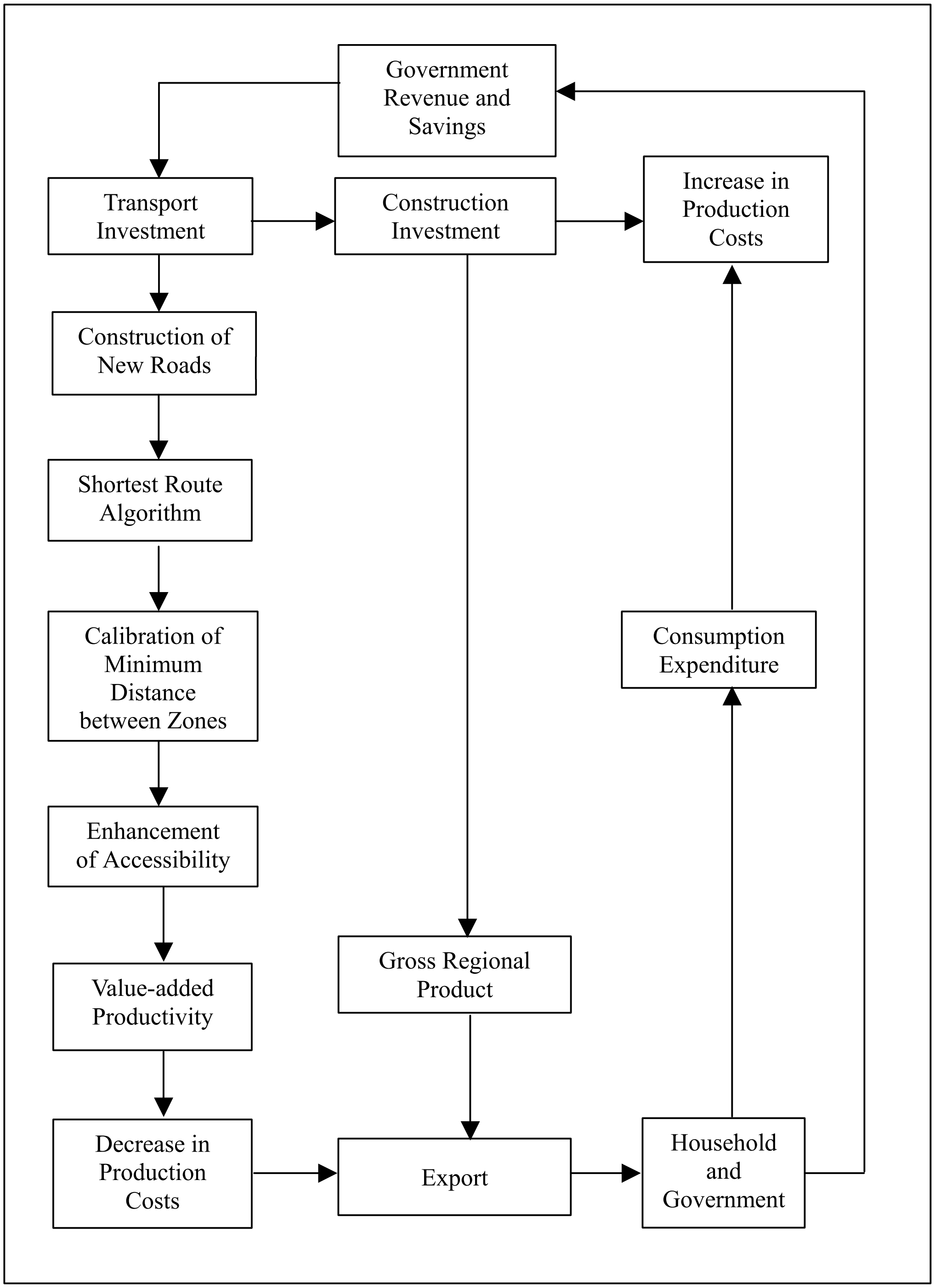

Fig. 2 Channel of impacts of transport investment on the economies

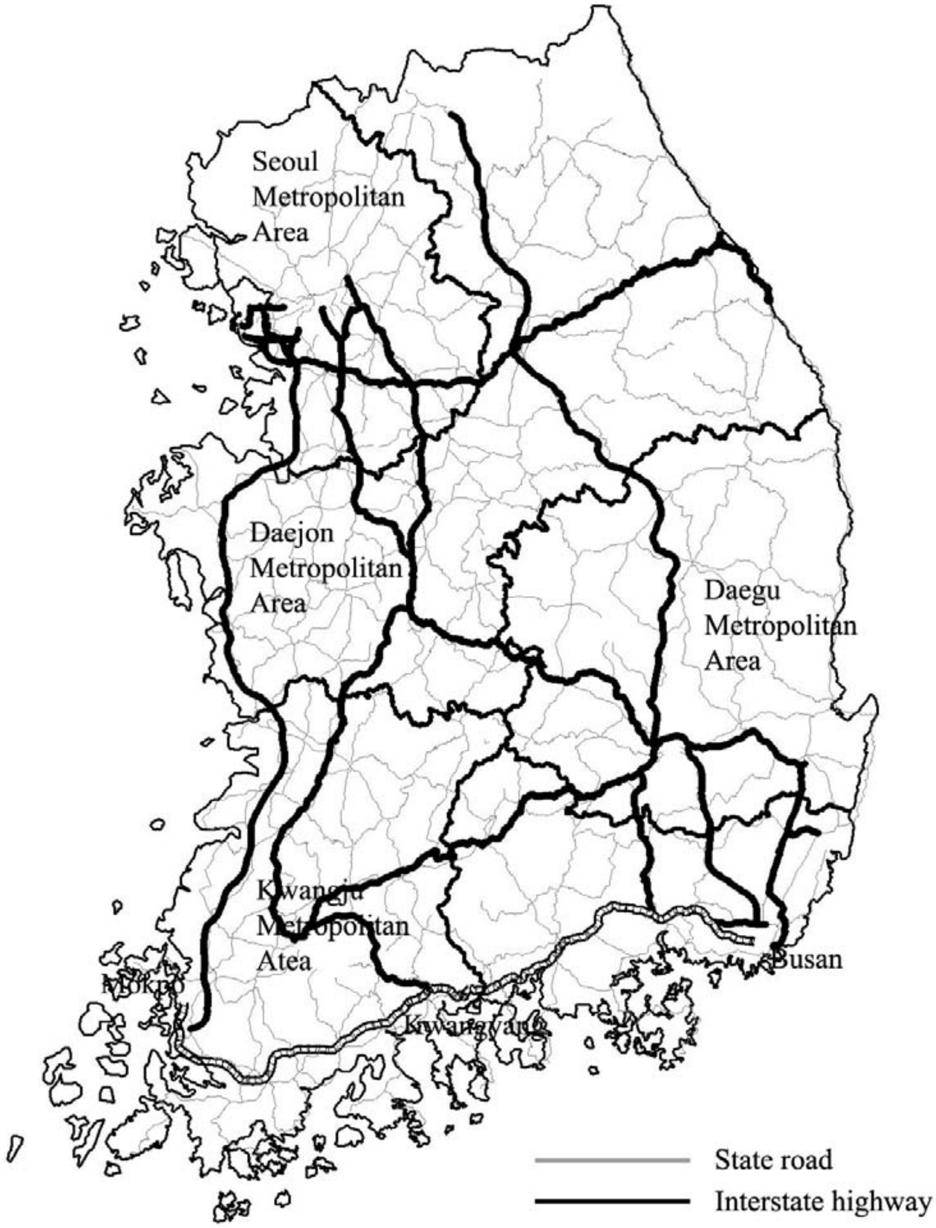

Fig. 3 Alternatives of highway construction

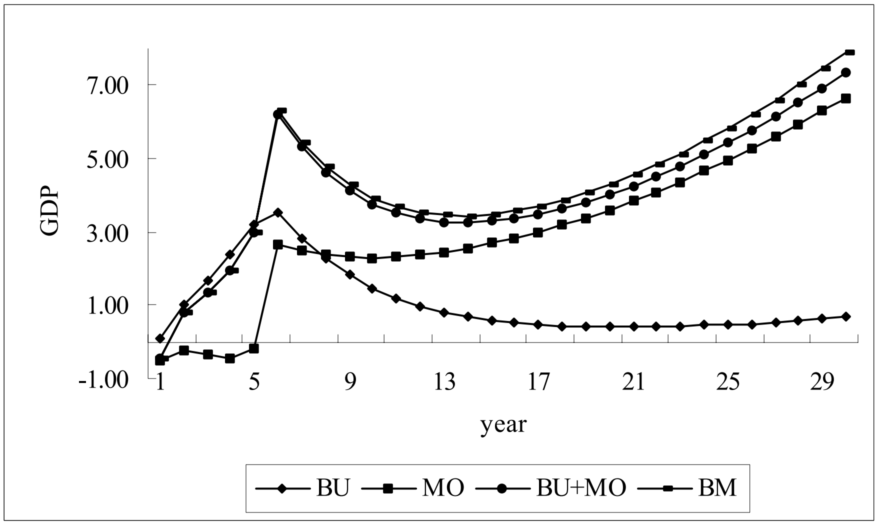

Fig. 4 Network effects of GDP

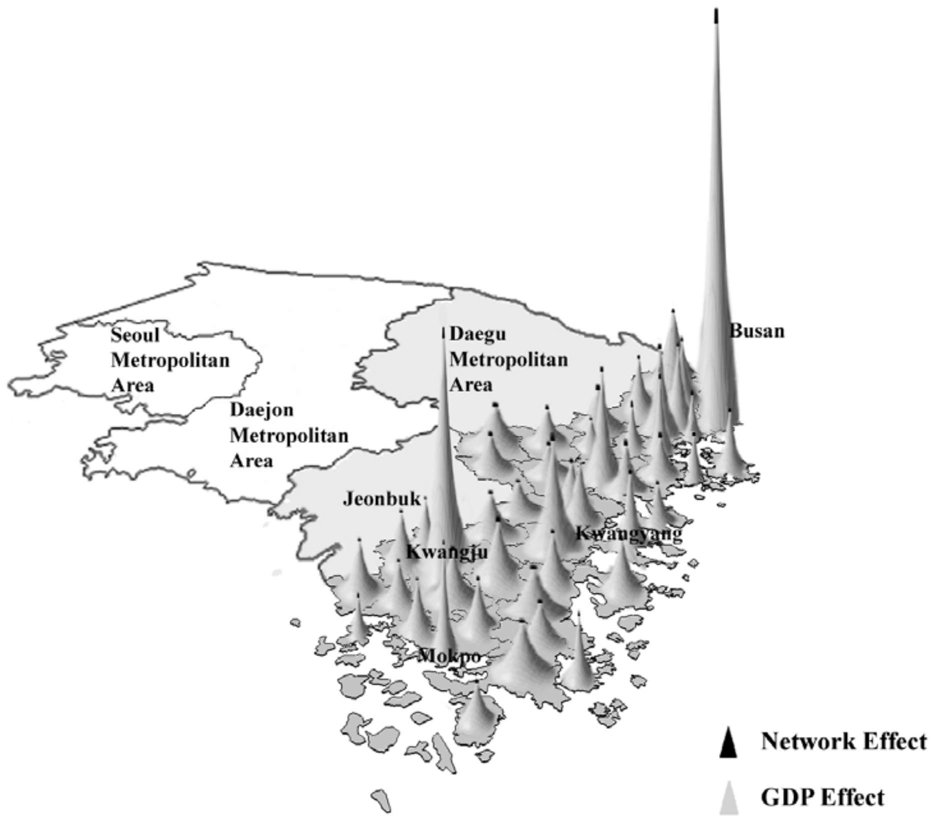

Fig. 5 Spatial distribution of incomes of Busan and Kwangju metropolitan areas

Table 1. Changes in accessibility index

	Base case	Alternative BK	Alternative KM	Alternative BM
Seoul	60.049	60.052	60.056	60.058
	(100)	(100.004)	(100.011)	(100.015)
Daejon	22.227	22.234	22.245	22.253
	(100)	(100.032)	(100.082)	(100.115)
Kwangju	15.404	15.462	17.196	17.375
	(100)	(100.378)	(111.639)	(112.799)
Daegu	18.877	18.879	18.913	18.922
	(100)	(100.009)	(100.187)	(100.235)
Busan	17.012	17.136	17.164	17.346
	(100)	(100.732)	(100.892)	(101.962)

note: The value (%) in the parenthesis is the ratio of the accessibility of each alternative to the base case.

Table 2. Annual average increases in value-added by region and sector (unit: billion US$)

		BK	KM	BK+KM (a)	BM (b)	(b)-(a)
Seoul	agriculture	-0.0009	-0.0271	-0.0280	-0.0297	-0.0017
	manufacturing	0.0101	0.1356	0.1457	0.1538	0.0080
	construction	0.0009	0.0047	0.0057	0.0060	0.0003
	services	0.0652	0.2128	0.2780	0.2894	0.0114
Daejon	agriculture	0.0023	-0.0241	-0.0218	-0.0235	-0.0017
	manufacturing	0.0267	0.1555	0.1821	0.1902	0.0080
	construction	-0.0001	0.0030	0.0030	0.0032	0.0002
	services	-0.0008	0.1679	0.1671	0.1788	0.0117
Kwangju	agriculture	0.0031	-0.5328	-0.5297	-0.5588	-0.0291
	manufacturing	0.1100	2.6381	2.7480	2.9115	0.1635
	construction	0.0055	0.0446	0.0501	0.0513	0.0011
	services	0.0018	-0.2553	-0.2535	-0.2890	-0.0355
Daegu	agriculture	0.0145	0.0161	0.0306	0.0334	0.0029
	manufacturing	0.1198	0.0722	0.1920	0.1980	0.0060
	construction	-0.0087	-0.0005	-0.0093	-0.0090	0.0002
	services	-0.0254	0.0707	0.0453	0.0515	0.0061
Busan	agriculture	0.0048	-0.1058	-0.1010	-0.1018	-0.0008
	manufacturing	-0.0281	0.4714	0.4433	0.5267	0.0834
	construction	0.0621	-0.0044	0.0577	0.0570	-0.0007
	services	0.6987	-0.0244	0.6743	0.6740	-0.0003

Table 3. Annual average increases in per capita incomes by region (unit: US$)

	BK	KM	BK+KM (a)	BM (b)	(b)-(a)
Seoul	3.70	18.52	22.22	23.27	1.05
Daejon	5.03	45.53	50.56	53.29	2.73
Kwangju	20.82	302.11	322.93	338.82	15.88
Daegu	16.38	26.33	42.71	45.23	2.52
Busan	107.48	49.44	156.91	168.90	11.99