AN APPLICATION OF AN INTEGRATED TRANSPORT NETWORK – MULTIREGIONAL CGE MODEL TO THE CALIBRATION OF SYNERGY EFFECTS OF HIGHWAY INVESTMENTS

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(Received 18 January 2008; In final form 30 August 2009)

A transportation network-multiregional CGE model is applied to estimate the synergy effects of a set of highway projects on value added by region and industrial sector. This synergy effect is defined as a difference between the summation of the net GDP increase from the development of each highway sub-link without spatial linkage and the change in GDP resulting from the concurrent development of all links with spatial linkages. Among nine east–west highways in Korea, the East–West 9 highway increases the GDP by 0.3% over the 30-year time period horizon, with 0.016% of the GDP due to the synergy effect. The East–West 9 highway has the largest synergy effect of US$0.164 billion per year on the manufacturing sector of Kwangju Metropolitan Area, resulting in a gain in a regional GRP per capita of US$15.88 per year. Since most synergy effects are generated in less developed regions, highway development can contribute to the reduction in regional disparities.

Keywords: Computable general equilibrium model; Transportation investment; Synergy effect; Regional social accounting matrix

1. INTRODUCTION

Transportation investment effects are composed of distributive and generative effects that induce a change in the spatial distribution of economic activities between regions and an increase in the economic value, respectively (van Exel et al., 2002). In terms of dynamics, such effects can be disaggregated into short term effects during the construction phase and long term effects during the operation phase of the transportation project (Kim et al., 2004). During the construction phase, the investments stimulate final demand, but generate 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.

Bröcker (2002) estimated the regional impacts of transportation costs and new road development of the Trans-European Transport-Networks (TEN-T) using a static Computable General Equilibrium (CGE) model for more than 800 regions. The reduction in transportation costs through road development could reduce the income disparity between regions. Haddad and Hewings (2001) analyzed the long-run regional effects of an increase
in total factor productivity in the transportation sector, resulting in the development of the
Brazilian Multisectoral and Regional/Interregional Analysis Model (B-MARIA). Haddad
and Hewings (2005) also found the asymmetric impacts that transportation investment had
on a spatial economy in which Sao Paulo was more able to exploit scale economies than
the rest of Brazil. They redeveloped the model B-MARIA-27 to capture non-constant
returns to scale for the manufacturing sector in each state, and the transportation
margins to account for the real costs of moving goods from one region to another. Kim
et al. (2004) developed a framework for economic analysis of highway projects that
was used to estimate the dynamic economic effects of a highway project on economic
growth and regional disparity in Korea. The framework was composed of a transport
model and a multiregional CGE model. The transport model measured changes in interre-
gional shortest distances and accessibility by the highway project, while the CGE model
estimated the spatial economic effects of the projects on GDP, prices, exports, and the
regional distribution of wages and population. It found that all of the highway projects
have positive effects on GDP and export growth as well as regional equity in terms of
wage and population.1

Kim et al. (2004) and Haddad and Hewings (2005) integrated transportation activity
with spatial and economic equilibrium approaches in a consolidated structure. They
succeeded in specifying the interactions between the transportation sector and real side
economy through a price mechanism, measuring transportation inputs in monetary
terms as well as other dimensions such as accessibility. The economic activities by
region and sector are differentiated with changes in the transportation network, which
has direct and indirect effects on both regional economic growth and interregional trade
patterns in the long term. They examined the regional economic impacts of a transport-
ation investment that was centered on a significant expansion of major highway routes
in Brazil and Korea. However, they failed to consider the synergy effects of the nearly
simultaneous development and expansion of these routes.

The purpose of this paper is to analyze the synergy effects of highway development on
national economic growth and spatial distribution of income in Korea. In this paper, the
synergy effect is defined as the difference between the incomes generated by the com-
pletion of all highway links and a simple sum of those by each sub-link in isolation.
Thus, the synergy effect is a net consequence from interactions among regions across
the network (van Exel et al., 2002). For the analysis of the synergy effect for transportation
facilities, the approach needs to estimate direct as well as indirect effects. The direct effect
is related to variation in the aggregated demand for the link. The indirect synergy effect is
a spillover effect determined by the organization of the network or linkages, relative
competitiveness of regions, and the mobility of factor inputs. Therefore, the estimation
of the synergy effect requires specification of the dynamic interactions between the
transportation network and regional economic performances in a fully integrated form.

This paper uses an integrated transport network model and multiregional Computable
General Equilibrium (CGE) model based on the study by Kim et al. (2004). As reviewed
above, the transport network model measures interregional minimum distances and acces-
sibility by highway project, while the CGE model estimates the spatial economic effects

1 See Tsuchiya et al. (2007) and Ando and Meng (2009) for recent studies linking transportation issues to econ-
omic performance by means of computable general equilibrium models.
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), Daejon MA (central area), Kwangju MA (southwest area), Daegu MA (upper southeast area), and Busan MA (lower southeast area), see Figure 3 below. Each MA is composed of large cities with populations exceeding one million inhabitants, and their associated provinces. The model specifies the behaviors of economic agents of 20 producers, five regional households, five regional governments, a central government, and the rest of the world. The model is applied to three highway development alternatives: (1) development of all links of the East–West 9 (EW9) highway to connect Mokpo in the Kwangju MA with Busan in the Busan MA; (2) development of the west-side link of the EW9 highway to pass through only the Kwangju MA; and (3) development of the east-side link of the EW9 highway to mainly pass through the Busan MA. In the next section, the model is presented, preceded by a brief review of the approaches to measure the synergy effects. Section 3 reveals the synergy effects of highway investment in Korea, while the final section summarizes the approach and suggests future directions.

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, and calculates highway accessibility for each transportation zone based on minimum distances and the population size. The multiregional CGE model estimates the economy-wide impacts of the highway development on spatial economies in a five-region division of the country. As discussed in Kim et al. (2004), a sizable body of literature has explored the 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; Seung and Kraybill, 2001; Haddad and Hewings, 2001; Conrad and Heng, 2002; and Bröcker, 2002). The framework of the multiregional CGE model in this paper is the same as that of the model used by Kim et al. (2004) with two differences, (1) in the regional classification and (2) in the specification of interregional trade. Kim et al. (2004) incorporated the 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 contacts with activities. It can be measured in terms of opportunity potential, 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 transportation projects using the economic potential approach of the accessibility variable. In this paper, the accessibility by region is derived from discounting the

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2 This section draws on Kim et al. (2004). See Appendix A for an overview of the equations, variables and parameters.
total number of interaction opportunities at all destinations by the sum of distances with
the arc and node impedances reflecting the quality of the highway network, while the
regional population is regarded as a proxy variable of the opportunity level at the destina-
tion (Martellato et al., 1998). Among a large number of accessibility alternatives in
Rietveld and Bruinsma (1998), the gravity type shown in Equation 1 has been widely
applied to European accessibility studies. Parameter $\beta$ in the equation is a travel distance
decay parameter that results from calibrating the 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 the 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 in
the transportation zone scale.

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

where

$ACC_i$: 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 con-
sumer 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. There are six economic regions
in the CGE model (five macro regions and the rest of the world). In each region, production
activity is divided into four industrial sectors: agriculture and mining, manufacturing, con-
struction, and services. While economic agents are composed of producers, households,
and government, each producer and household is assumed to be a price-taker, choosing
an optimal set of factor inputs and commodity demands under the maximization principles
of constrained profit and private utility, respectively. However, 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 the cross hauling attributed to commodity
heterogeneity and the aggregation problem into account. Thus, the commodities that
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 product destination.

In the model, the production structure consists of three stages (see Figure 1). At the top
of the structure, the gross output by region and sector is determined as a two-level pro-
duction function of value added and composite intermediate inputs. That is, the producer
chooses quantities of the intermediate demands and value added using fixed proportions of gross output (according to a Leontief production technology). This specification allows for substitution among labor, capital, and accessibility of the transportation services, but no substitution among the intermediate inputs and production factors. This formulation is based on the non-sequential partial equilibrium model discussed in Kim et al. (2004). 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 the potential use of the highway infrastructure into account (Rietveld and Bruinsma, 1998). The producer also requires an optimal set of labor and capital inputs in order to produce a given level of
added value and 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 mobile within sectors, 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, 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 total labor demand with total labor supply, which is fixed for each period. In the model, population growth equals the natural growth of the lagged population size plus net immigration.

Immigration is assumed to proceed in response to interregional differences in the Gross Regional Product (GRP) per capita and the population of two regions, reflecting the spirit of Todaro (1994). In the Todaro model, migration relies on differences in expected incomes in order to explain continued migration in the presence of open unemployment. The migrants examine the probability of finding jobs and the interregional gap in real wages, and compare the present value of the earnings stream in one region with the present value of the expected earnings stream in other competing regions. They decide to stay or move to the region to achieve the maximum level of expected benefit based on the cost-benefit analysis. As a result, the major determinants of migration in the Todaro model are employment opportunities and wage levels.

In the second stage, the intermediate demands are transformed into demands for domestic products and foreign imports. We use an Armington approach to distinguish commodities by industry and by place of origin using a small open economy assumption, specifying the imperfect substitutability between the commodities. 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 domestic sales, the price of the domestic product relative to the domestic price of foreign imports, and the two key parameters of share and elasticity of substitution.

At the final stage, the demand for the intraregional product is determined by the price and total demand for 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 gross output into two competing commodities, domestic supplies and foreign exports. The domestic supplies include both intraregional supplies and regional exports. The ratio of foreign exports to gross output depends on the relative ratio of the domestic product price to the domestic price of foreign exports, the share parameter, and the elasticity of transformation under revenue maximization.

The total demand for goods and services by region and industry consists of intermediate demands, total household consumption expenditures, 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 are 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 of household incomes and value added items. In addition, the national government transfers payments to 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 investment. 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 the total domestic investment to the net national savings plus net capital inflows. The sectoral allocation of total investment by destination is endogenously determined by the capital price for each sector and the allocation coefficient of investment, and is transformed into sectoral investment by origin through a capital coefficient matrix.

The average cost pricing rule is applied to the price level determination that is obtained by clearing any excess demand in labor, capital, and commodity markets (Gottinger, 1998). This price adjustment is required for the Walrasian equilibrium condition, and every price is measured in relative scale. There are two major price variables in the CGE model; composite commodity prices on the demand side and gross output prices on the supply side. The composite commodity price is the market price at which consumers pay for regional commodities and services, and is a weighted average of the domestic product price and the domestic price of the foreign import. The gross output price is the marketed output value at which producers sell their products, and is composed of the primary factor payment and marginal costs of the intermediate inputs.

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) satisfies this condition, tracking the purchases and expenditures of services and commodities. We use a revised SAM, described by Kim et al. (2004), modified 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 behavioral parameters. The structural coefficients are point estimates or non-elasticity parameters derived from the SAM and cross-sectional survey data, including various tax rates and consumption propensities. The behavioral parameters are derived from historical data, 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 within-period and between-period models. The within-period model 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 multiple periods and updates 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 equations 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 equations under convexity. The exogenous variables include world market prices, population, and government expenditure, and the foreign exchange price in nominal terms is set as the *numeraire* of the model. The numerical specification of the model is discussed in detail by Kim et al. (2004).

Since the CGE model is not stochastic but deterministic, it is hard to estimate the economic effects with a confidence limit. However, the reliability of the CGE model can be examined by the comparison of the simulation results with actual values or the stability of the results over time (De Maio et al., 1999). The former is not proper for this simulation, because the impact analysis of highway development in this paper is a kind of counterfactual analysis and time-series data are not ready for comparison studies. In the case of the latter, the robustness of the results with respect to key parameter values can be assessed by sensitivity analysis (Bandara and Coxhead, 1999). In this paper, the GDP and the consumer price index could be reduced by 1.86–3.52% and 0.21–6.27%, respectively, if the elasticities of substitution and transformation for Armington and CET functions increase by 10% in the model. This shows that the simulation results are not very sensitive to the elasticity values and the model is comparatively reliable for the counterfactual analysis.

As discussed above, the perfect competition assumption is made for the economic behavior of producers and consumers while imperfect competition is applied to the interregional commodity flows, migration, and international trades. The model could be modified into a monopolistic competition model with increasing returns to scale and imperfect competition. The simulation results tend to depend on the types of assumptions such as Cournot competition with homogeneous products, Eastman–Stykolt collusive behavior, and Cournot competition with differentiated products (Kim and Kim, 2003).

In summary, the transport network model calculates an interregional minimum distance matrix and an accessibility index for each highway project. The investment expenditures and the accessibility level are applied to the multiregional CGE model, which can calibrate the effects of the highway project on the spatial economic growth (Figure 2).

### 3. SYNERGY EFFECTS OF HIGHWAY INVESTMENT

The transportation network-multiregional CGE model is applied to estimate the synergy effects of the highway project on value added by region and industrial sector during construction and operation periods. The proposed national highway system of Korea may be characterized as a grid-type structure of 6160 km consisting of seven highways in the North–South direction and nine highways in the East–West direction, all of which are expected to be completed by 2020 (Kim et al., 2004). The East–West 9 (EW9) highway was selected for a counterfactual analysis of the synergy effect in terms of the data available and the degree of completion (see Figure 3). The origin and destination of the highway are the city of Busan in Busan MA and the city of Mokpo in 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 synergy effects of the highway, EW9 was divided into two sub-links to 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:

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

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

*Alternative BM*: construction (Busan and Mokpo) of all EW9 highway links.
On average, the cities and counties linked with the EW9 highway sub-link between Busan and Kwangyang (alternative BK) have a higher population density (1248.58 person per km$^2$), employment per capita (28.76%), and tax per capita (US$1015.59) than the other cases.

There are two kinds of temporal effects that the transportation infrastructure generates on economic sectors.$^3$ One is a short-term effect, caused by a change in construction

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$^3$ Due to the various reactions of economic agents to the change in the transportation network, it is impossible to define clearly the phase in terms of years.
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-term 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 changes in accessibility depend not only on the location but also the connectivity of the highway with others, and are capitalized as added value by region and industry through the relocation of economic activities to the place that maximizes utility and profit levels (Shefer and Shefer, 1999; Banister and Berechman, 2000). These changes in accessibility and economic shock generate a set of new equilibrium values for regional production, population, and prices, satisfying the price normalization rule that is subject to the exogenous foreign exchange rate. The counterfactual simulation for a 30-year span is performed for each alternative where the construction and the operation periods are assumed to be five and 25 year periods, respectively. Since the short term effect is generated by the construction investments, the effect lasts for five years. The long term effect comes into action from the sixth year with transforming the investment into 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 intertemporal consistency for the periods under the existing circumstances without the construction of the highway. In this paper, the synergy effect is defined as a difference between the GDP from the alternative BM and the sum of the GDP from the BK and KM alternatives. The GDP and the construction and operation costs are measured in 1995 constant prices. The government finances construction costs through an imposition of an earmarked tax on household and producer incomes. 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 the 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 in 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, highway development can lead to a higher level of accessibility for Kwangju MA (18.922), the lowest one in the base case, rather than Busan MA (17.346).

Market sizes can grow with increases in the interregional trade volumes and migration, once the transportation costs decrease due to the development of a highway network. This

Table 1. Changes in accessibility index.

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

Note: The value (%) in the parenthesis is the ratio of the accessibility of each alternative to the base case.
generates reductions in composite commodity prices and gross output prices, thus having positive effects on regional incomes at a constant price. Higher incomes of regional households result in higher outputs and domestic demands including imports, while the improved price competitiveness stimulates foreign export demands. In a sense that these regional economic effects depend on the regional economic structure and the degree of interregional competition (complementarity), the net spatial effects are determined by substitution effects for primary factor inputs and exports/imports among regions, and income effects of regions with better accessibilities (Haddad and Hewings, 2005). For example, economic agents try to maximize utilities or profits by changing industrial and residential locations, input substitution, and the spatial organization of production in response to a new accessibility level (Parr et al., 2002). Improvements in accessibility for regions with lower per capita incomes may yield continued advantages to existing regions, enabling firms located there to expand production, and the realization of scale economies and lower transportation costs to penetrate markets that were formerly economically inaccessible. During this process, firms in these peripheral regions may not be able to compete as effectively. However, evidence from Japan and the US suggests that the reduction of transport costs may induce an important change in the spatial organization of production (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, thereby reaping scale economies at each stage of production without incurring significant transportation costs in moving the intermediate commodity from one establishment to another.

If the accessibility levels and the construction investments by region for the EW9 highway are fed into the multiregional CGE model, the GDP at 1995 constant prices would increase by US$129.393 billion or 0.3% of GDP, over the 30-year time horizon. The sub-links of Busan-Kwangyang and Kwangyang-Mokpo also could increase the GDP by US$31.847 billion and US$90.540 billion, respectively. Summing the net increase in the GDP from the development of each sub-link over the two cases without spatial linkage, the net GDP increase would amount to US$122.387 billion. This value could be compared with the change in GDP resulting from the concurrent development of the EW9 highway with spatial linkages, and the difference between them, which is US$7.006 billion $ (0.016% of the GDP). The difference can be regarded as the synergy effect from the connectivity of the two sub-links.

The increases in the GDP during the operation periods in Figure 4 are defined as the sum of GDP increases by (1) the construction investments and (2) the improvement of total factor productivity through the reduction in travel costs as shown in Figure 5. They are not non-monotonous over time since they first fall, and then rise again. The former effect decreases over time due to the completion of highway construction, while the latter increases with time. The marginal decrease of the GDP by the construction investments is larger than the marginal increase by the positive growth of the total factor productivity until the 14th year, after which the net change in the GDP continues to increase.

The EW9 highway has the largest impact on value added value of the manufacturing sector of Kwangju MA, increasing it by US$2.912 billion on average per year over 30 years in Table 2. Since the production inputs are intersectorally allocated to maximize the profits under the neoclassical closure rule of the labor market, the value added effect cannot be positive for every industrial sector. For example, the effect on the value added of the agricultural sector would be negative, decreasing it annually from US$0.559 billion to US$0.102 billion in all MAs except for Daegu MA. In Daegu MA,
only the construction sector experiences a loss of US$0.009 billion per year over the 30 year period. For the Seoul and Busan MAs, among the production sectors, the service sector derives more benefits from the highway network development, while the manufacturing sectors are the major beneficiaries in the other three MAs.

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Sector</th>
<th>BK</th>
<th>KM</th>
<th>BK + KM (a)</th>
<th>BM (b)</th>
<th>(b)-(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoul</td>
<td>agriculture</td>
<td>-0.0009</td>
<td>-0.0271</td>
<td>-0.0280</td>
<td>-0.0297</td>
<td>-0.0017</td>
</tr>
<tr>
<td></td>
<td>manufacturing</td>
<td>0.0101</td>
<td>0.1356</td>
<td>0.1457</td>
<td>0.1538</td>
<td>0.0080</td>
</tr>
<tr>
<td></td>
<td>construction</td>
<td>0.0009</td>
<td>0.0047</td>
<td>0.0057</td>
<td>0.0060</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>services</td>
<td>0.0652</td>
<td>0.2128</td>
<td>0.2780</td>
<td>0.2894</td>
<td>0.0114</td>
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In terms of synergy effects by region and industrial sector, there are substantial increases in the manufacturing sectors of Busan MA and Kwangju MA, as noted for their impact on GDP. For the Kwangju MA, the EW9 highway results in a gain from the synergy effect on the manufacturing sector of US$0.164 billion per year, but this is partially offset by negative synergy effects on the agricultural sector (–0.029 billion US$ per year) and the service sector (–0.036 billion US$ per year). For Busan MA, the annual synergy effect of US$0.083 billion in the manufacturing sector is generated at

**FIGURE 4.** Synergy effects of GDP.
the expense of the synergy effects in the other three sectors by approximately US$0.001 billion. Similarly, the agricultural sector generates a negative synergy effect in the Seoul and Daejon MAs, but no effect in Daegu MA.

Table 3 reports the impacts on GDP per capita. The completion of the EW9 highway induces an increase of the GRP per capita of Kwangju MA by US$338.82 per year. It also raises the GRP per capita of Busan MA by US$168.90, Daejon MA by US$53.29, Daegu MA by US$45.23, and Seoul MA by US$23.27. If the synergy effect is measured by the GRP per capita, the EW9 highway project would have the highest synergy effect on the Kwangju MA, generating a GRP per capita increase of US$15.88 per year. The second and third cases are Busan MA (US$11.99 per year) and Daejon MA (US$2.73 per year), respectively. In a sense that the synergy effect occurs in the less developed regions, such as the 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.

4. SUMMARY AND FURTHER RESEARCH DIRECTIONS

In this paper, a transportation network-multipurpose CGE model is applied to estimate the synergy effects of a highway project on the value added by region and industrial sector,
during both the construction and operation periods. Among seven highways in the North–South direction and nine highways in the East–West direction, the East–West 9 highway increases GDP by 0.3% over a 30-year horizon and generates 0.016% of the GDP as a synergy effect. In addition, the EW9 highway has the largest synergy effect on the manufacturing sector of Kwangju MA (a US$0.164 billion increase per year, resulting in a regional GRP per capita gain of US$15.88 per year). Since more synergy effects are generated in the less developed regions, such as Kwangju MA, rather than the developed regions, the highway development can obviously contribute to a reduction in regional income disparities.

Regarding further research directions, efforts to extend the model could be focused on the specification of the interactions between the transportation network model and the multiregional CGE model. In the current model, there is no feedback mechanism to incorporate travel demand factors, such as the income and 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 classifications: there are 132 transportation zones in the transport network model and five macro regions in the multiregional CGE model, respectively. One solution to this problem would be to allocate the endogenous variable values of the macro regions into those of the micro regions, using the Dendrinos-Sonis model or spatial interaction model for each variable. Another option 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. In addition, the economic behavior of regional agents needs to be specified by the supply and demand of sectoral land such as industrial, residential, commercial, agricultural, and green land uses. In terms of production and utility, industrial and commercial land uses could provide land for mining and manufacturing production and the service sectors, respectively, and the supply of residential land use 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 production structure — technologically and spatially — of firms within Korea. Will these transportation investments generate a hollowing out process (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? Furthermore, will this transportation investment result in the assembly of a finished product much more efficiently and cheaply than if production was concentrated within the Seoul region? Analysis paralleling that for Japan (Hitomi et al., 2000) would add some important insights into the potential for such processes to be realized and thus provide an even stronger motivation for continuing transportation network investment strategies.

Acknowledgements

The first version of paper was presented at the 42nd Southern Regional Science Association in Louisville, KY, 10–12 April, 2003. The work is supported by the Korea Research Foundation Grant (KRF-2005-079-BS0157).
References


APPENDIX A. THE MULTIREGIONAL CGE MODEL

A1. Equations

1. Production

\[ INT^r_i = \sum_r \sum_j i_{ij}^r X^r_i \]  
\[ X^r_i = VA^r_i + INT^r_i \]  
\[ \ln VA^r_i = AD^r_i + \beta_{10}^r (\ln R^r)^2 + \beta_{12}^r \ln L^r_i \ln R^r + \beta_{13}^r \ln KAP^r_i \ln R^r + \beta_{14}^r \ln R^r + \beta_{15}^r \ln L^r_i + \beta_{16}^r \ln KAP^r_i + \beta_{17}^r (\ln L^r_i)^2 + \beta_{18}^r (\ln KAP^r_i)^2 \]  
\[ + \beta_{19}^r \ln L^r_i \ln KAP^r_i \]  

2. Labor Market

\[ WA^{wdist}_i = PVA^t_i (\beta_{15}^r + 2 \beta_{17}^r \ln L^r_i + \beta_{12}^r \ln R^r + \beta_{13}^r \ln KAP^r_i) \]  
\[ P^t_i = ng^t_i P^t_{i-1} + \sum_s MIG^{rs} - \sum_r MIG^{rs} \]  
\[ \sum_i L^r_i = LD^r \]  
\[ LD^r = P^r ldp^r \]  
\[ \ln(MIG^{rs}) = \beta_0 + \beta_1 \ln(P^r) + \beta_2 \ln(P^s) + \beta_3 \ln \left( \frac{YLC^{rs}}{P^r} \right) - \beta_4 \ln \left( \frac{YLC^{rs}}{P^s} \right) - \beta_5 \ln(d^{rs}) \]
3. **Exports and Imports**

\[ X_i^r = A T_i^r [\gamma_i^r E X_i^r d_i^r + (1 - \gamma_i^r) X D_i^r d_i^r]^{1/d_i^r} \]  \hspace{1cm} (A9)

\[ \text{Max} \quad P E_i^r E X_i^r + P D_i^r X D_i^r \]  \hspace{1cm} (A10)

\[ \frac{E X_i^r}{X D_i^r} = \left[ \frac{P E_i^r}{P D_i^r} \right]^{1/d_i^r - 1} \]  \hspace{1cm} (A11)

\[ Q_i^r = A_i^r [\delta_i^r IM_i^r d_i^r + (1 - \delta_i^r) XD_i^r d_i^r]^{-1/d_i^r} \]  \hspace{1cm} (A12)

\[ \text{Min} \quad PM_i^r IM_i^r + PD_i^r XD_i^r \]  \hspace{1cm} (A13)

\[ \frac{IM_i^r}{X D_i^r} = \left[ \frac{PD_i^r}{PM_i^r} \right]^{\delta_i^r - 1} \]  \hspace{1cm} (A14)

\[ TIM = \sum_r \sum_i p w m_i^r IM_i^r \]  \hspace{1cm} (A15)

\[ TEX = \sum_r \sum_i p w e_i^r E X_i^r \]  \hspace{1cm} (A16)

4. **Household Sector**

\[ C O_i^r = \sum_s C D_{i s}^r \]  \hspace{1cm} (A17)

\[ Y L C^r = \sum_i W A_i^r L_i^r \text{ wdist}_i^r \]  \hspace{1cm} (A18)

\[ Y K C^r = \sum_i (P V A_i^r V A_i^r (1 - \text{ itax}_i^r) + ISUB_i^r - \text{ depr}_i^r PK_i^r K A P_i^r - WA_i^r \text{ wdist}_i^r L_i^r) \]  \hspace{1cm} (A19)

\[ Y F A C T^r = Y L C^r + Y K C^r \]  \hspace{1cm} (A20)

\[ Y H^r = Y L C^r + Y K C^r + Y S U B^r \]  \hspace{1cm} (A21)

\[ Y T A X^r = \text{ htax}^r Y H^r \]  \hspace{1cm} (A22)

\[ Y S A V^r = \text{ hasv}^r (Y H^r - Y T A X^r) \]  \hspace{1cm} (A23)

\[ Y D^r = Y H^r - Y T A X^r - Y S A V^r \]  \hspace{1cm} (A24)

\[ P C_i^r C D_i^r = c m a t_i^r Y D^r \]  \hspace{1cm} (A25)

\[ U^r = \prod_{i,s}(C D_{i s}^r) \]  \hspace{1cm} (A26)
5. Government Sector

\[
GR = TARIFF + INDTAX + YTTAX \tag{A27}
\]

\[
TARIFF = \sum_i IM_t^r \cdot ER (1 + tm_t^r) \tag{A28}
\]

\[
INDTAX^r = \sum_i itax_t^r \cdot PVA_t^r \cdot VA_t^r \tag{A29}
\]

\[
YTTAX = \sum_r YTAX^r \tag{A30}
\]

\[
YSAV = \sum_r YSAV^r \tag{A31}
\]

\[
GR = GCTOT + GSAVE + YSUB \tag{A32}
\]

\[
GCTOT = \sum_r \sum_i \sum_s GC_{sr}^r \tag{A33}
\]

\[
GC = GC_{rs}^r \cdot GC_{et}^i \tag{A34}
\]

\[
GC = \sum_i GC_{sr}^r \cdot GC_{et}^i \cdot GCTOT \tag{A35}
\]

\[
SUB = ITSUB + HTSUB \tag{A36}
\]

\[
ITSUB = itsub \cdot GCTOT \tag{A37}
\]

\[
HTSUB = htsubp \cdot GCTOT \tag{A38}
\]

\[
TOTSAV = \sum_r YSAV^r + \sum_r \sum_i depr_i^r \cdot PK_i^r \cdot KAP_i^r 
+ FSAVER + GSAVE \tag{A39}
\]

\[
DEPRICIA = \sum_r \sum_i depr_i^r \cdot PK_i^r \cdot KAP_i^r \tag{A40}
\]

\[
Q_i^r = IND_i^r + CO_i^r + INO_i^r + \sum_s GC_{sr}^r \tag{A41}
\]

A2. Variables

- \( CD_{rs}^i \): private consumption expenditure
- \( CO_i^r \): total private consumption expenditure
- \( ER \): nominal foreign exchange rate (Korean won per dollar)
- \( EX_i^r \): foreign export
- \( FSAV \): foreign saving
- \( GC_{sr}^r \): consumption expenditure of local government
- \( GCTOT \): government current expenditures
- \( GR \): government revenues (expenditure)
- \( GSAVE \): government savings
- \( IM_t^r \): foreign import
- \( IND_i^r \): intermediate uses
A3. Parameters

$cmats_{ir}$ budget share of households for the goods of industry $i$ of region $s$ by region $r$

d_{rs} distance between region $r$ and region $s$

dep_t depreciation rate

gces_{irs} regional government consumption

gcet_{irs} government consumption
$hsav^r$ saving rate of household  
$htax^r$ direct tax rate  
$htsub$ gross subsidy rates of household  
$imat_{ir}^r$ investment matrix  
$io_{i}^{t}$ technical input-output coefficient  
$itax_{i}^{t}$ indirect tax rate  
$itsub$ gross subsidy rates of industry  
$ldp$ labor demand in region $r$  
$ng_{r}^{t}$ natural growth of population of region $r$ in the year $t$  
$pwe_{i}^{t}$ export price in world market  
$pwm_{i}$ import price in world market  
$tm_{i}^{r}$ tariff rate  
$wdist_{i}^{r}$ wage adjustment parameter