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AN OPTIMIZING MODEL OF EDUCATION AND ECONOMIC PLANNING FOR KOREA

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I. INTRODUCTION

Education has been widely accepted as an important factor in economic development. However, the education sector differs from others in many ways. Thus "the types of signals available in the market economy (prices, profits) are either not observable in the educational case or must be calculated in some manner" (see Cohn [1972]). Due to incomplete knowledge of the profitability of educational investment, it is possible that the optimal allocation of resources cannot be guaranteed in the economy. In addition, an imbalance between labor supply and demand at a given moment could occur because individuals cannot precisely predict the level of future labor demand. These arguments provide the rationale for educational planning. Sen [1970] grouped the educational planning approaches into 4 categories as follows:

1) The fixed requirements approach
2) The income shares approach
3) The rate of return approach
4) The programming approach

The fixed requirements approach would be to estimate the educated manpower by occupation for each sector of the economy (Parnes [1962], Tinbergen and Bos [1964]).

Let E_i = the demand for manpower of type i
X_i = the level of output of each sector i

There is then a functional relation, which completely determines

$E_i : E_i = f_i(X).$

This can be rewritten as

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$$E_i = \Sigma_j a_{ij} \cdot X_j.$$

where a_{ij} represents the amount of manpower of type i required to produce a unit of output of sector j. This approach would be acceptable only if it is impossible to produce the same output with varying combinations of factors, that is, if no substitution possibilities (see Sen [1970]). However, a major drawback with this approach is that nonsubstitutability is not likely to exist in the real world. This approach gives a "single prediction of expected manpower and educational needs." Since an equilibrium process requires a "given interaction of both supply and demand forces, changes in factors affecting educational supply should be considered" (see Cohn [1972]).

The framework of the income shares approach is based on a neoclassical production and distribution model (see Denison [1962]).

Let h_i = production factor i
X_j = the level of output j
q_i = the price of factor i
p_j = the price of output j
m_{ij} = the marginal product of factor i in producing output j
s_i = the relative share of factor i in the total value output

From well-known marginal productivity theory, the factor price is determined as the value of the marginal product. Thus

$$q_i = p_j \cdot m_{ij}.$$

And

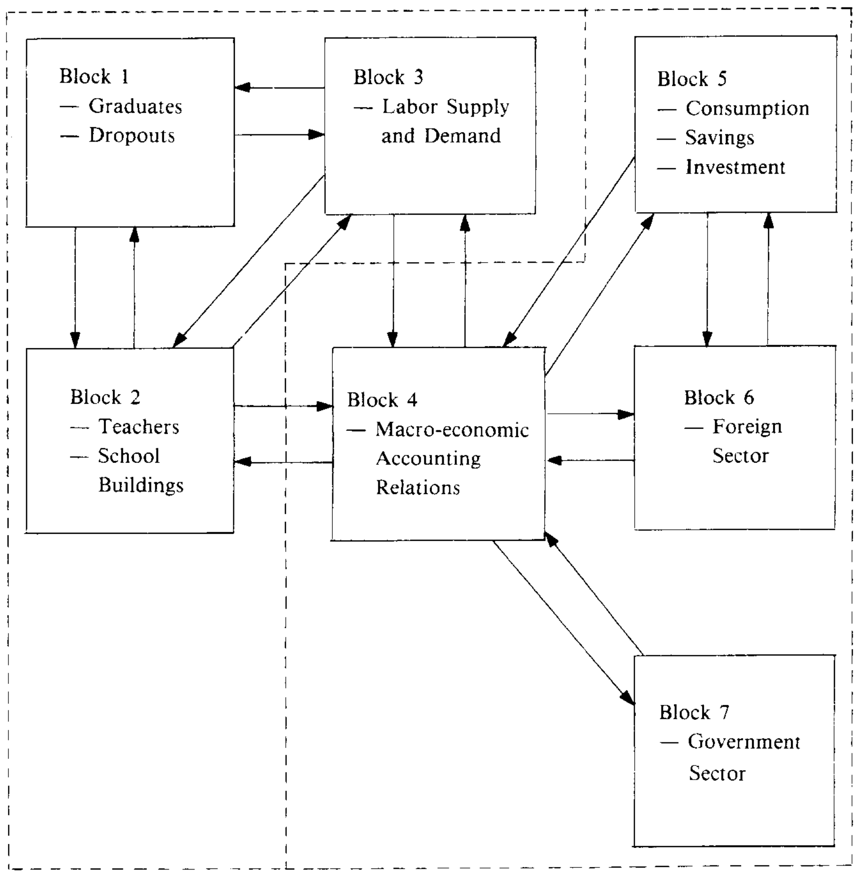
$$s_i = q_i \cdot h_i / p_j \cdot X_j = m_{ij}/(X_j/h_i).$$

The right-hand side in the equation of the relative share of factor s_i represents the elasticity of output with respect to the productive factor i. While this approach provides a "basis for the estimation of the contribution of education, as in Denison, it is criticized because the factor price is equal to only the private marginal product, not the so-called social marginal product" (see Sen [1970]). Sen argues that the social marginal product with externalities should be considered in development planning because the contribution of education to the social and economic atmosphere may be extremely important in the developing countries.

The rate of return approach is based on the net present value of the future income stream that results from being educated (see Becker [1964], Harberger [1965]). Future income streams and costs should be discounted through an appropriate discount rate. The education program for which net present value is positive is considered worthwile; a program for which net present value is zero or negative would be considered not worthwhile. However, all ther relevant costs, "including the cost involved in forgoing the opportunity of working and earning a salary while being educated," should be carefully calculated in applying this approach (see Sen [1970]). Since the rate of return approach "employs past data to predict present relative relationships, its projection may not be justifiable for long-run planning" (see Cohn [1972]). In addition, it is also criticized for estimating only "the rate of return for the marginal project, in other words, for the education of a small additional group of people" (see Sen [1970]).

The programming approach used in educational planning consists of maximizing some objective function, subject to a set of constraints which specify the production functions for the education system and the availability of various educational inputs, as well as several constraints expressing restrictions on the productive sectors in the economy (see Adelman [1966], Bowles [1967], Charnes et al. [1970], Kendrick [1974], Lagana and Galan [1985, 1987]). The interest of this programming approach lies not only in the solutions of the model which indicate "the best set-up for the educational system," but also in the relevant policy for other sectors of the economy from sensitivity analyses (see Cohn [1972]). While applying the programming approach to educational planning problems, the works of Adelman [1966], Charnes et al. [1970], Kendrick [1974], and Lagana and Galan [1985, 1987] are related to the fixed requirements approach. The work of Bowles [1967], however, is developed from the rate of return approach and utilizes the linear programming approach. Therefore the criticisms levelled at the rate of return approach are applicable to the Bowles model, while the criticisms of the fixed requirements approach are applied to the works of Adelman, Charnes et al, Kendrick, and Lagana and Galan. However, Sen [1970] concludes that the programming approach is perhaps the most promising among them; three advantages of this approach are that 1) "in posing the problem as one of optimization rather than consistency, it begins well, for educational plans may be consistent and still be very inferior," 2) it allows much wider assumptions in specifying the economic constraints and objective functions 3) it not only furnishes "a more rational direct basis of planning" but also presents "the shadow prices, the economic meaning of which are important and relevant for planning decisions."

During the period 1962-1986 Korea devised and carried out 5 Five-Year Economic Development Plans. Economic planning models that backed up the Economic Development Plans during those years did not attempt to link the education system with the entire economic system in one model. The primary purpose of this paper is to build an intertemporal multi-sectoral model of the labor force to enable the investigation of the interrelations among the education system, labor supply and the economy in Korea. In this study, some of the mathematical formulations draw on the latest programming model, which was applied to the Mexican economy, by Lagana and Galan [1985]. While Lagana and Galan consider



Structure of the Model

the labor variables by occupation and by education level, they assume a zero elasticity of substitution between different levels of education within each sector, as well as between different occupational groups within each sector. Obviously a good census of occupations is required to consider such labor variables in a long-term projection model. It seems inappropriate to consider such labor variables in this paper, because Korea is expected to undergo extensive changes in its industrial structure and experience high job mobility in the coming 10 years. This means that the distribution of occupations is expected to be unstable. It therefore seems reasonable to consider labor supply by education level in this model.

This paper is basically designed 1) to help the reader understand a mathematical formulation of the programming model and 2) to analyze some directional flows of the model's results in experimental runs. The model's solutions are not intended to serve as a basis for policy recommendations, given the level of aggregation and the strong assumptions used. Rather, this model could be viewed as the first step toward creating a long-term projection model that is sufficiently disaggregated to forecast future education and economic situations more precisely.

The planning model developed here is a linear programming model with an input-output structure. The planning horizon covers the 10 years from 1990 to the year 2000 in two time periods of five years each. The model consists of two submodels, an education submodel and an economic submodel, which consider 5 education levels and 4 productive sectors, respectively (see Structure of the Model). The objective function maximizes total discounted GDP for the period from 1990 to the year 2000, subject to a set of interdependent linear constraints; the model provides the optimal levels of endogenous variables within the feasible solution range in each period.

This paper is divided into 4 sections. The second section discusses the mathematical formulation of the model. The three main parts of the model specification—sets, constraints and objective function—are presented in detail. The computational methods and the main results of the base case model and experimental runs are presented in Section 3, which contains the results for graduates by education level, teachers by education level, school building by education level, sectoral employment and total labor supply, sectoral group output, and foreign trade. Section 3 also presents the discussion of the alternative runs for sensitivity analyses on some policy parameters. The sensitivity analyses consider the following parameters: the education investment ratio, lower and upper bounds on exports, the production efficiency ratio. Some limitations and further improvements of the model are explicitly discuss in the final section.

II. THE MATHEMATICAL MODEL

In this section a linear intertemporal programming model is developed for labor supply planning through the education system. The optimization model, which has an input-output structure, covers a planning horizon of 10 years (2 time periods of 5 years each) and considers 5 education levels and 4 industry sectors. The model consists of two submodels: an education submodel and an economic submodel.

The education submodel includes a set of relations for graduates and dropouts, a set of equations for teachers and school buildings and a set of constraints for education and labor employment. The economic submodel includes a set of macroeconomic accounting relations, a set of constraints for consumption, savings, and investment, a set of foreign sector equations, a set of government sector equations and a set of macroeconomic identities. The objective function maximizes total discounted GDP, subject to these interdependent constraints. The model determines the optimal levels of endogenous variables within the feasible solution range in each period.

1. Sets Specification

N(=R) Set of educational levels

Elementary: Elementary education has six grade levels.

Middle : Middle school education has three grade levels. Only elementary school graduates can enter the middle school.

Highschool: High school education has three grade levels. Only middle school graduates can enter high school. In this model general and vocational high schools are aggregated into the high school education level. High school graduates can enter either vocational college or a university.

Voccollege : Vocational college education has two grade levels. Only high school graduates can enter the vocational college.

University : University education has four grade levels. Either high school graduates or two-year vocational college graduates can enter the university level. In this model the normal university and post-graduate levels are aggregated into the university level.

I = Set of productive sectors

Primary : Agriculture, forestry, fishing.

Secondary: Mining, manufacturing.

Socapital : Electricity, gas, water, construction, transportation, storage, communication.

Services : Wholesale and retail stores, hotels, finance, insurance, real estate, social and personal services.

T = Set of planning years

1: 1985 (base year)

2: 1990

3: 1995

4: 2000

List of Parameters

$a_{i,j,t}$: input-output coefficient matrix

α_1 : average propensity to consume by sector

$b_{i,j}$: capital-output ratio by sector of origin

$\beta p_{n,t}$: target ratio of graduates and teachers

$\beta s_{n,t}$: target ratio of graduates and school buildings

$C_{n,ni}$: promotion matrix

X : average propensity to spend

Xs_l : sectoral share of total government consumption

$\delta_{l,t}$: sectoral labor-output ratios

el : lower limit on sectoral exports

eu : upper limit on sectoral exports
ε_n : graduation rates by education level
η : discount rate
$EX^{sb}_{l,t}$: target level of exports by sector
$f_{n,r}$: teaching force matrix
Y_l : estimated coefficient of investment by sector
h_l : row correction factor
hc : promotion ratio from high school to junior vocational colleges
hu : promotion ratio from high school to universities
ι : minimum share of education investment
k : average propensity to save
λ_n : rate of reentering the education system after dropping out
μ^p_r : minimum number of demand for new teachers per graduate
μ^s_r : minimum level of demand for new buildings per graduate
υ : minimum share of investment in new school buildings
Ω_t : average cost of a school building
ϕ_i : average propensity to import by sector
π_i : annual rate of labor substitution
$\phi_{n,t}$: promotion rate by education level
$q_{n,r}$: demotion matrix
ϱ_l : annual rate of technological change
σ^p_r : retirement rate of teachers by education level
σ^s_n : depreciation rate of school buildings by education level
θ : number of years per time period
v : average retirement rate of labor force
ξ_l : labor requirement ratio per unit output
ζ : average tax rate
Z^{85}_n : dropouts entering the labor force in the base year
P^{85}_r : stock of teachers in the base year
$Pl^{d85}_{n,r}$: average increase of teachers in the base year
S^{85}_n : stock of school building in the base year
S^{m85}_n : average increase of school buildings in the base year
WP_{d85_n} : graduates entering the labor force, including teachers
L^{d85}_n : labor force by education level in the base year

List for Endogenous variables
$G^r_{n,t}$: graduates by education level
$G^c_{n,ni,t}$: graduates entering the next-higher education level
$D_{n,t}$: dropouts by education level
$D^r_{n,t}$: dropouts reentering the education system
$Z_{n,t}$: dropouts entering the labor force
$P_{r,t}$: stock of teachers by education level

$Pl_{n,t}$: graduates entering the labor force as teachers
$Pl^{d}_{n,r,t}$: entrants to the teaching force
$S_{n,t}$: stock of school buildings by education level
$S^{m}_{n,t}$: additions to school buildings by edcuation level
$NINQ_t$: total increase in school buildings
$NINV_t$: investment in new school buildings in value terms
IED_t : total investment in education
$E^{s}_{i,t}$: sectoral employment
E^{w}_{t} : total employment
TLF_t : total labor force
$L^{d}_{n,t}$: labor force by education level in year t
$W_{n,t}$: graduates entering the labor force, except for teachers
$WP^{d}_{n,t}$: graduates entering the labor force
X_t : total gross output
$X^{s}_{i,t}$: sectoral gross output
GDP_t : gross domestic product
YD_t : disposable income
CP_t : total private consumption
$CP^{s}_{i,t}$: sectoral private consumption
CG_t : total government consumption
$CG^{s}_{i,t}$: sectoral government consumption
INV_t : total investment
$INVO_{i,t}$: investment by sector of origin
$INV^{s}_{i,t}$: investment by sector of destination
SAV_t : total domestic saving
EX_t : total exports
$EX^{s}_{i,t}$: sectoral exports
IM_t : total imports
$IM^{s}_{i,t}$: sectoral imports
$FSAV_t$: foreign saving
NFI_t : net factor income
DISY : total discounted gross domestic product

2. Education and Labor Supply Submodel

A. Block 1: Graduates and Dropouts

A-1. Distribution of Graduates

(1)	$G^{r}_{n,t}$	=	$\Sigma_{ni\ NI}\ C_{n,ni} \cdot G^{c}_{n,ni,t}$	+	$W_{n,t}$
	graduates of level n		graduates from level n entering level ni		graduates from level n entering the labor force, except for teachers

+	$Pl_{n,t}$ graduates from level n entering the labor force as teachers

where N = set of education levels
T = set of representative planning years
$C_{n,ni}$ = matrix of promotion to higher education level

A-2. Promotion

(2) $\Sigma_{ni \varepsilon NI} C_{n,ni} \cdot G^c_{n,ni,t}$ graduates from level n entering level ni	=	$\psi_{n,t}$ promotion rates		$G^r_{n,t}$ graduates of level n

A-3. Promotion to Higher Education

(3) $G^c_{highschool,voccollege,t}$ high school graduates entering junior vocational colleges	=	(hc/hu) ratio of promotion to higher education		$G^c_{highschool,university,t}$ high school graduates entering universities

A-4. Distribution of Dropouts

(4) $D_{n,t}$ dropouts from level n in year t	=	$Z_{n,t}$ dropouts from level n entering the labor force	+	$D^r_{n,t}$ dropouts reentering the education system

A-5. Reentering the Education system

(5) $D^r_{n,t}$ dropouts reentering the education system	=	λ_n rate of re-entrance after dropping out		$D_{n,t}$ dropouts from level n in year t

A-6. Dropouts

(6) $D_{n,t}$ dropouts from level n in year t	=	$((1/\varepsilon_n) - 1)$ ((1/graduation rates) − 1)		$G^r_{n,t}$ graduates of level n in year t

B. Block 2: Teachers and School Buildings

B-1. Teachers

(7)	$P_{r,t}$	=	$(1-\sigma^{p}_{r})\theta$	$\cdot\ P_{r,t-1}$	+	$\theta\cdot\Sigma_{n\varepsilon N} f_{n,r}\cdot Pl^{d}_{n,r,t-1}$
	teachers in year t		(1-retirement rate)	teachers in year t-1		entrants to the teaching force

with the initial conditions $P_{r,1985} = P^{85}_{r}$, $Pl^{d}_{n,r,1985} = Pl^{d85}_{n,r}$

where $P_{r,t}$ = stock of teachers by type of school in year t

$Pl^{d}_{n,r,t}$ = yearly additions to the teaching force

σ^{p}_{r} = retirement rate of teachers by type of school

θ = number of years per time period

$f_{n,r}$ = matrix of entrants to the teaching force

B-2. Graduates and Teachers

(8)	$G^{r}_{n,t}$	=	$\beta^{p}_{n,t}$	$P_{n,t}$
	graduates of level n in year t		target ratios between graduates and teachers	teachers of level n in year t

B-3. Demand for Teachers

(9)	$\Sigma_{n\varepsilon R} f_{n,r}\cdot Pl^{d}_{n,r,t}$	=	$\mu^{p}_{r}\cdot G^{r}_{r,t}$
	entrants to the teaching force		demand for new teachers

where $\mu^{p}_{r} = (P_{r,t} - P_{r,t-1}) / G^{r}_{r,t}$

B-4. Increase in School Teachers

(10)	$Pl_{n,t}$	=	$\Sigma_{r\in R} f_{n,r}\cdot Pl^{d}_{n,r,t}$
	graduates from level n entering the labor force as teachers		entrants to the teaching force

B-5. School Buildings

(11)	$S_{n,t}$	=	$(1-\sigma^{\delta}_{n})^{\theta}$	$S_{n,t-1}$	+	$\theta\cdot S^{m}_{n,t-1}$
	schools in year t		(1-depreciation rate)	schools in year t-1		additions to schools

with the initial conditions $S_{n,1985} = S^{85}_{n}, S^{m}_{n,1985} = S^{m85}_{n}$

where $S_{n,t}$ = stock of school buildings by type of school in year t

$S^{m}_{n,t}$ = additions to school buildings in year t

σ^{δ}_{n} = depreciation rate of school buildings

B-6. Graduates and School Buildings

(12) $$G^{r}_{n,t} \leqslant \beta^{d}_{n,t} \quad S_{n,t}$$

$G^{r}_{n,t}$	$\leqslant$	$\beta^{d}_{n,t}$	$S_{n,t}$
graduates of level n in year t		target ratios between graduates and buildings	school buildings of level n in year t

B-7. Demand for School Buildings

(13) $$S^{m}_{n,t} \geqslant \mu^{d}_{n} \cdot G^{r}_{n,t}$$

$S^{m}_{n,t}$	$\geqslant$	$\mu^{d}_{n} \cdot G^{r}_{n,t}$
increase in school buildings		minimum levels of demand for new school buildings

where $\mu^{d}_{n} = (S_{n,t} - S_{n,t-1}) / G^{r}_{n,t}$

B-8. Increase in School Buildings

(14) $$\Sigma_{n \in N} S^{m}_{n,t} = NINQ_{t}$$

$\Sigma_{n \in N} S^{m}_{n,t}$	$=$	$NINQ_{t}$
sum of all types of school buildings added in year t		total increase in school buildings in year t

B-9. Conversion Equation

(15) $$NINQ_{t} = (1/\Omega_{t}) \quad NINV_{t}$$

$NINQ_{t}$	$=$	$(1/\Omega_{t})$	$NINV_{t}$
total increase in school buildings in year t		inverse average cost of one school building	investment in new school buildings in value terms

where Ω_{t} = average cost of one school building

B-10. Investment in Education

(16) $$IED_{t} \geqslant \iota \quad GDP_{t}$$

IED_{t}	$\geqslant$	ι	GDP_{t}
total investment in education		minimum share of investment in education	gross domestic product

B-11. Investment in New School Buildings

(17) $$NINV_{t} = \nu \quad IED_{t}$$

$NINV_{t}$	$=$	ν	IED_{t}
investment in new school buildings in value terms		minimum share of total investment in school buildings	total investment in education

C. Block 3. Relations between Education and Employment

C-1. Demand for Labor

(18)	$E^{s}_{i,t}$	$=$	$\delta_{i,t}$	$X^{s}_{i,t}$
	sectoral employment		sectoral labor-output ratios	sectoral output

C-2. Total Employment

(19)	E^{w}_{t}	$=$	$\Sigma_{i \in I} E^{s}_{i,t}$
	total employment		sum of sectoral employment

C-3. Demand and Supply for Labor

(20)	E^{w}_{t}	$\leqslant$	TLF_{t}
	total employment		total labor force

C-4. Total Labor Force by Education Level

(21)	TLF_{t}	$=$	$\Sigma_{n \in N} L^{d}_{n,t}$
	total labor force		sum of labor force by education level n

C-5. Labor Force after Graduation

(22)	$W_{n,t}$	$+$	$Pl_{n,t}$	$=$	$WP^{d}_{n,t}$
	graduates from level n entering the labor force, except for teachers		graduates from level n entering the labor force as teachers		graduates entering the labor force

C-6. Labor Force by Education Level

(23)	$L^{d}_{n,t}$	$=$	$(1-v)^{\theta} \cdot L^{d}_{n,t-1}$	$+$	$\theta \cdot (WP^{d}_{n,t-1} + \Sigma_{r \in R} q_{n,r} \cdot Z_{n,t-1})$
	labor force by education level in year t		labor force by education level in year t-1		additions to the labor force by education level

with the initial conditions $L^{d}_{n,1985} = L^{d85}_{n}, WP^{d}_{n,1985} = WP^{d85}_{n},$

$$Z_{n,1985} = Z^{85}_{n}$$

where v = retirement rate of the labor force
$L^d_{n,t}$ = labor force by education level in year t
$WP^d_{n,t}$ = entrants to labor force from the education system
$Z_{n,t}$ = entrants to the labor force from dropping out in year t
$q_{n,r}$ = demotion matrix of dropouts joining labor force

3. Economic Submodel

A. Block 1: Macroeconomic Accounting Relations

A-1. National Accounts Identity

(24)

GDP_t	=	CP_t	+	CG_t	+	INV_t
gross domestic product		total private consumption		total government consumption		total investment

	+	EX_t	−	IM_t
		total exports		total imports

A-2. Commodity Balances by Sector

(25)

$X^s_{i,t}$	+	$IM^s_{i,t}$	$\geqslant$	$\Sigma_{j \in J} S_{i,j,t} \cdot X^s_{j,t}$	+	$CP^s_{i,t}$
sectoral gross output		sectoral imports		sectoral intermediate demand		sectoral private consumption demand

+	$CG^s_{i,t}$	+	$INVO_{i,t}$	+	$EX^s_{i,t}$
	sectoral government consumption demand		investment by sector of origin		sectoral exports

where I = set of productive sectors

A-3. Investment Requirements

(26)

$INVO_{i,t}$	=	$\Sigma_{j \in J} b_{i,j}$	$INV^s_{j,t}$
investment by sector of origin		capital-output coefficient	investment by sector of destination

B. Block 2: Consumption, Saving and Investment

B-1. Disposable Income

(27)	YD_t	$=$	GDP_t	$(1-\zeta)$
	disposable income		gross domestic product	(1-average tax rate)

B-2. Total Private Consumption

(28)	CP_t	$=$	$(1-k)$	YD_t
	total private consumption		(1-average propensity to save)	disposable income

B-3. Sectoral Private Consumption Demand

(29)	$CP^{s}_{1,t}$	$=$	α_1	CP_t
	sectoral private consumption		average propensity to consume	total private consumption

B-4. Total Domestic Saving

(30)	SAV_t	$=$	k	YD_t
	total domestic saving		average propensity to save	disposable income

B-5. Investment and Saving

(31)	INV_t	$\leqslant$	SAV_t	$+$	$FSAV_t$
	total investment		total domestic saving		foreign saving

B-6. Sectoral Investment

(32)	$INV^{s}_{i,t}$	$=$	ν_i	$(X^{s}_{i,t} - X^{s}_{i,t-1})$
	sectoral investment		estiamted parameter	difference of sectoral output between year t and year t-1

C. Block 3: Foreign Sector

C-1. Sectoral Exports Bounds

(33)	$\theta l \cdot EX^{sb}_{i,t}$	$\leqslant$	$EX^{s}_{i,t}$	$\leqslant$	$\theta u \cdot EX^{sb}_{i,t}$
	lower limit on sectoral exports		sectoral exports		upper limit on sectoral exports

C-2. Balance of Payments

(34)	IM_t	$-$	EX_t	$\leqslant$	$FSAV_t$	$+$	NFI_t
	total imports		total exports		foreign saving		net factor income

C-3. Sectoral Imports

(35)	$IM^{s}_{i,t}$	$=$	ϕ_i	$\cdot$	$X^{d}_{i,t}$
	sectoral gross imports		average propensity to import		sectoral outputs

D. Block 4: Government Sector

D-1. Government Consumption Expenditure

(36)	CG_t	$=$	X	$\cdot$	GDP_t
	total government consumption		average propensity to spend		gross domestic product

D-2. Sectoral Government Consumption Expenditure

(37)	$CG^{s}_{i,t}$	$=$	X^{s}_{i}	$\cdot$	CG_t
	sectoral government consumption		sectoral share of total government consumption		total government consumption

E. Block 5: Macroeconomic Definitions

E-1. Total Gross Output

(38) $X_t = \Sigma_{i \in I} X^s_{i,t}$

total gross output = sum of sectoral gross output

E-2. Total Imports

(39) $IM_t = \Sigma_{i \in I} IM^s_{i,t}$

total imports = sum of sectoral imports

E-3. Total Exports

(40) $EX_t = \Sigma_{i \in I} EX^s_{i,t}$

total exports = sum of sectoral exports

E-4. Total Investment Demand

(41) $INV_t = \Sigma_{i \in I} INV^s_{i,t}$

total investment = sum of sectoral investment

4. Objective Function

(42) $\max DISY = \Sigma_{t \in T} GDP_t \cdot (1/1+\eta)^{\theta \cdot t-1}$

sum of discounted gross domestic product

III. EMPIRICAL RESULTS

This section presents the results of the base case model discussed in Section II. In view of the level of aggregation, the model solutions in this section should not be considered to be perfect forecasts over the next 10 years. Rather, this model could be the first step toward creating a long-term projection model that is sufficiently disaggregated to forecast future education and economic situations more precisely. Thus, the primary interest is not to analyze the particular solutions in this model exhaustively, but to study the directional flows of the model's solutions under alternative policies.

1. Computational Methods

The model was solved using the optimization lanquage GAMS (General Algebraic Modeling System), on the IBM 3081 computer system at the University of Texas at Austin. This new economic modeling language, which was developed by Alexander Meeraus of the World Bank, considerably decreases the time and effort required to construct and use multi-sectoral models.

The base case model consists of
46 blocks of constraints; 430 single constraints
38 blocks of variables; 344 single variables.

In order to solve this intertemporal optimization programming model, some variables require predetermined initial conditions for the base year 1985. In the base model initial conditions for the variables—such as the existing stock of teachers and school buildings, the number of labor force by education level, the number of graduates entering the labor force by education level and sectoral gross output for the year 1985—were taken from published data (see the Ministry of Education (1986), Economic Planning Board (1986), the Bank of Korea (1987)). The projected level of exports, assumed to grow at an annual rate of 8.5% during the years 1990-2000 after due consideration of various domestic and the external environment, were provided exogenously in the model (see Korea Development Institute (1985), the Bank of Korea (1985)).

2. Prospects for Education and Labor Force

The number of graduates at all education levels except elementary school are expected to rise during the entire planning period (see Table 3.1). The number of graduates from elementary schools is projected to grow until 1995, then to decline slightly in 2000. Because of free compulsory elementary education and the government's implementation of an automatic promotion policy in elementary schools, this decline of graduates in elementary school is caused principally by demographic change, that is, a declining birth rate for Korea in the latter half of the 1970s.

The number of graduates at the middle school level grows from 787 thousand in 1990 to 812 thousand in 2000. The number of middle school graduates is projected to outnumber the number of graduates from elementary schools in 2000. This is attributable both to the government's plan for free compulsory middle school education and to changes in the population structure. With gradual increases in the number of graduates for middle and high school education, it could be said that secondary education has planted its roots deeply in Korea.

Since the high ratios of students to teachers at various levels of education in

[**Table 3.1**] Levels of educational variables

(in thousands)

		Year		
		1990	1995	2000
Graduates	Elementary	795	815	806
	Middle	787	808	812
	High School	656	657	697
	Voccollege	107	143	183
	University	226	269	278
Teachers	Elementary	133	144	155
	Middle	84	93	100
	High School	84	100	111
	Voccollege	9	13	18
	University	37	53	70
School Buildings	Elementary	138	166	183
	Middle	75	86	97
	High School	74	92	108
	Voccollege	15	21	29
	University	69	96	126
Employment	Primary	3446	3200	2930
		(19.9)*	(16.5)	(13.6)
	Secondary	4438	5028	5612
		(25.7)	(25.9)	(26.0)
	Socapital	1994	2283	2512
		(11.5)	(11.7)	(11.7)
	Services	7409	8906	10492
		(42.9)	(45.9)	(48.7)
Total Employment		17288	19417	21546
Total Labor Force		18225	20345	22380
Unemployment Rate (%)		5.1	4.6	3.7

*: The figures in parentheses represent the sectoral shares of total employment.

Korea as compared with the other countries has long been noted, additional recruitment of teachers at all education level is required to promote the quality of education. Although the number of graduates of elementary schools is expected to grow slowly and then decrease somewhat during the years 1990 to 2000, the number of elemntary school teachers would have to increase continuously at an annual rate of 1.5% in order to attain the target level for the student/teacher ratio (see Korean Educational Development Institute (1986)). In order to meet the rapidly rising demand for higher education which began in the early 1980s, the teaching forces at higher education institutions is projected to increase at the relatively rapid pace of 7.0% for junior vocational colleges and 6.6% for the university level (see Table 3.1).

School classes at all education levels have been overcrowded. In particular, the student/school building ratios at both secondary and higher education levels have worsened due to continuous growth at those levels since the early 1970s. Table 3.1 shows the level of school buildings by education level for the next 10 years. During the planning period, the number of school buildings is projected to increase continuously at all education levels just as the teaching force does. Together with the rapid expansion of higher education opportunity in Korea, school buildings are projected to increase quickly at an annual rate of 6.8% for junior vocational colleges and 6.3% for the university level. Because the growth rates of the school buildings are higher than those of the graduates, the condition for education, in terms of physical input, gradually improves at all education levels during the years 1990 to 2000.

Since the Korean economy continues to grow at a rapid rate, the employment structure in the years 1990 to 2000 is expected to be similar to the employment structure commonly seen in advanced industrialized countries. The most dramatic change in the employment structure will be that primary sector employment will decrease from 3,446 thousand in 1990 to 2,930 thousand in 2000 (see Table 3.1). Accordingly, the share of the primary sector in total employment should decrease from 19.9% in 1990 to 13.6% in 2000; this means that the ratio of employment in the primary sector to total employment will be comparable to ratios in the Western industrialized countries by the year 2000. In addition, the services sector's share of total employment is projected to rise from 42.9% in 1990 to 48.7% in 2000, while the shares of secondary and social overhead capital sectors will remain nearly unchanged. Employees leaving the primary sector are mostly absorbed into the services sector during the years 1990 to 2000. This is partly due to 1) fast substitution of labor for capital in the secondary sector and 2) diversification in the services sector resulting from substantial growth of income and the standard of living (see Korea Development Institute (1985)).

3. Economic Perspectives

Table 3.2 shows levels of macroeconomic variables used in the solution of the model. From the supply side, GDP is anticipated to grow at an annual rate of 7.1% during the years 1990 to 2000. Even though the projected growth rate is somewhat less than the rate achieved in the first half of the 1980s, such sustained economic growth can foreseeably be attained through technological development and domestic resource mobilization. From the demand side, the level of consumption is projected to grow at a rate of 7.1% during the years 1990 to 2000 because of increased government consumption expenditure for social development, such as housing, medical care, education and social security. The level of total exports is projected to grow at an annual rate of 8.1% during the planning period, while total imports are expected to increase at an annual rate of 6.8% during the same

[**Table 3.2**] Macroeconomic Variables

(in trillions of 1980 won)

		Year		
		1990	1995	2000
Macroeconomic Variables	GDP	79.4	114.1	157.5
	Imports	31.8	44.8	61.3
	Consumption	54.7	78.5	108.4
	Investment	24.5	33.1	40.6
	Exports	32.1	47.3	69.8
Gross Output	Primary	15.9	24.2	35.8
	Secondary	100.8	140.8	190.8
	Socapital	31.1	42.8	55.7
	Services	43.6	61.4	83.3
Exports	Primary	0.9	1.3	1.9
	Secondary	24.1	35.5	52.4
	Socapital	4.3	6.3	9.3
	Services	2.8	4.2	6.2
Imports	Primary	3.2	4.8	7.1
	Secondary	26.9	37.6	50.9
	Socapital	0.8	1.2	1.5
	Services	0.9	1.3	1.7
Trade Surplus		0.3	2.5	8.5
Trade Dependency Ratios to GDP (%)	Exports	40.4	41.5	44.3
	Imports	40.1	39.3	38.9

period.

While gross output is projected to rise at an annual rate of 6.7% during the planning period, gross output in the primary sector increases from 15.9 trillion won in 1990 to 35.8 trillion won in 2000, which implies that the primary sector grows at a rate of 8.4%. This rapid growth is caused by improvement in productivity in the primary sector, which comes from structural changes and such advances as genetic engineering. Gross output in the secondary and social overhead capital sectors, which exhibited rapid growth in the past, is expected to increase steadily at rates of 6.6% and 6.0% between the 1990 and 2000 years, respectively. With the recent widespread eruption of dissatisfaction—resulting from large income disparity between urban and rural areas—the social overhead capital sector, which includes water supply and drainage, transportation and communication systems, is expected to be expanded in order to improve the productivity and welfare of the population in rural areas and small towns.

Table 3.2 presents a summary of the level of foreign trade in the model. As exports continue to grow rapidly, the high trade dependency will be deepened for the coming 10 years. The ratio of total exports to GDP will rise from 40.4% in

1990 to 44.3% in 2000. It has been pointed out that the domestic economy can undoubtedly be influenced by cyclical fluctuations from abroad due to this high level of trade dependency. It has also been pointed out that excessive resource allocation to the export sector as a development strategy may be counterproductive (see Hutchison (1987)).

Since the growth rate of total imports is somewhat lower than the growth of GDP, the ratio of total imports to GDP will decrease from 40.1% in 1990 to 38.9% in 2000. The share of imports in both primary and secondary sectors out of the total remains about 95% during the planning period. If the domestic economy is to grow at a fast rate, this high level of import dependency might be inevitable for Korea, a country poorly endowed with natural resources. As a result of the relatively slow increase in imports, the trade surplus is expected to widen rapidly, from 0.3 trillion won in 1990 to 8.5 trillion won in 2000.

4. Results from Experimental Runs

Differences in projections when key policy parameters are changed are useful for policy making. As mentioned earlier, sensitivity analyses consider the following parameters: the education investment ratio, lower and upper bounds on exports, the target level of exports, the production efficiency ratio.

Minimum education investment in the base case, which is directly related to an increase of school buildings, is greater than 8.5% of gross domestic product. In this alternative run (Case 1) the minimum ratio of education investment to GDP (ι) is increased to 9.0%.

	Year	ι
Case 1	1990-2000	0.09

The following table compares the number of school buildings at elementary schools for the base case and the alternative run.

	School buildings at elementary schools (in 1000)		
		Year	
	1990	1995	2000
Base Case	138	166	183
Case 1	138	165	190

Although there are few changes at other education levels, the number of school buildings at elementary schools increases fairly rapidly during the years 1990 to 2000. This is because the activity level at elementary schools is invariant to activity levels at other education levels (middle schools, high schools, junior vocational colleges and universities) in maximizing the objective function.

Although Hutchison (1987) states that reliance on export expansion has been a successful development policy in the past, he also indicates that continued resource commitments to the export sector relative to the nonexport sector would be counter-productive for the future Korean economy. In other words, continued expansion of the export sector as a share of total production could soon distort resource allocation so as to impede further economic growth. Consequently, he suggests that a more balanced, market-oriented development strategy would be appropriate for the next stage of rapid economic progress. In the base case the constraints on sectoral exports are all tight at the lower bound during the entire planning horizon. This seems to be because the target level of exports is set too high for the open economy. In order to test Hutchison's suggestion, an alternative run was made using the following experiment, modifying both lower(el) and upper(eu) bounds on exports:

Case 2: el = 0.96; eu = 1.04
Case 3: el = 0.98; eu = 1.02

The table below compares annual GDP growth rates for the base case with those generated by alternative runs.

	GDP Growth Rate (% per year)	
	1990-1995	1995-2000
Base Case	7.5	6.7
Case 2	7.9	6.9
Case 3	7.1	5.7

In Case 2, most of the results on sectoral exports are still tight at the lower bound. However, the annual GDP growth rates in Case 2 are faster than those in the base case. In Case 3, the results on sectoral exports are all tight at the lower bound. However, the annual GDP growth rates in Case 3 are slower than those in the base case. From the above experiments it can be seen that values for macroeconomic variables may be increased even though the target level of exports is decreased. Then the following question arises:

To what extent should the target level of exports be reduced so as to maximize total discounted gross domestic product?

In order to answer this question, several experiments on the target level of exports were conducted:

Case 4: To reduce by 2 percentage points the target level of exports
Case 5: To reduce by 4 percentage points the target level of exports
Case 6: To reduce by 6 percentage points the target level of exports

[**Table 3.3**] GDP*

(in trillions of 1980 won)

	Year		
	1990	1995	2000
Base Case (187.7)**	79.4	114.1	157.5
Case 4 (193.4)	80.9	119.7	161.5
Case 5 (194.1)	82.1	119.6	159.8
Case 6 (192.7)	81.4	119.7	157.6

*: The alternative runs with different rates of reduction for the target level of exports.
**: The figures in parentheses are total discounted gross domestic product.

Table 3.3 shows the results on GDP for these alternative runs. The experiments demonstrate that lowering the target level of exports in the base model increases total discounted gross domestic product. Total discounted GDP increases until the target level of exports is reduced by 4 percentage points, and decreases if the target level of exports is reduced by 6 percentage points or more. Therefore it is desirable to reduce the target level of exports by approximately 4 percentage points in order to maximize total discounted GDP. Table 3.4 compares the results for the most important macroeconomic variables in Case 5 of a 4 percentage point reduction of the target level of exports with the base case. As is clear in Table 3.4, the levels of all macroeconomic variables are greater than those in the base

[**Table 3.4**] Comparison of Macroeconomic Variables

(in trillion of 1980 won)

	Year		
	1990	1995	2000
Base Case			
Supply	111.3	158.9	218.7
GDP	79.4	114.1	157.5
Imports	31.8	44.8	61.3
Demand	111.3	158.9	218.7
Consumption	54.7	78.5	108.4
Investment	24.5	33.1	40.6
Exports	32.1	47.3	69.8
Case 5***			
Supply	114.7	166.5	223.2
GDP	82.1	119.6	159.8
Imports	32.7	46.9	63.4
Demand	114.7	166.5	223.2
Consumption	56.5	82.3	109.9
Investment	27.3	35.9	42.1
Exports	30.9	48.2	71.1

***: The alternative run with a 4 percentage point reduction for the target level of exports.

[**Table 3.5**] GDP*

(in trillions of 1980 won)

	Year		
	1990	1995	2000
Base Case	79.4	114.1	157.5
Case 7	80.2	116.5	163.3
Case 8	84.0	130.7	180.2
Case 9	84.8	128.8	188.8

*: The alternaive runs with different rates of decrease for intermedia inputs.

case results during the years 1990 to 2000, except for the level of exports in 1990. Exports are lower by 3.6% in 1990 as compared with the base case, greater by 1.9% both in 1995 and 2000. Moreover, the exports constraints are not tight at the lower bound in 1995 and 2000. GDP in this run is also greater: by 3.3% in 1990, by 4.9% in 1995 and by 1.5% in 2000.

As economic efficiency improves, more outputs are produced with a given unit factor cost. As a result, factor income improves. In turn, increased purchasing power due to improved factor income induces additional production. Therefore, the present experiment involves policy analysis with the objective of increasing economic efficiency by eliminating inefficient elements in production activities or in the economic structure. For practical analysis, output multiplier effects obtained by improving production efficiency are measured by reducing the intermediate input ratios from the technical coefficients of the base year in all sectors. In brief, the experimental runs are as follows:

Case 7: rho(i) = 0.005
Case 8: rho(i) = 0.01
Case 9: rho(i) = 0.005; rho ("secondary") = 0.02

Here rho(i) represents the annual average rate of decrease of intermediate inputs in sector i. In Case 9 the annual rate of decrease of intermediate inputs from the base year's input-output coefficient matrix is assumed to be at 0.5% in the primary, social overhead capital and services sectors, and at 2% in the secondary sector. Table 3.5 shows the results of GDP for these alternative runs. When the ratio of intermediate inputs is decreased at an annual rate of 0.5% in all sectors, GDP is slightly higher during the entire period as compared with the base case. Case 8, a doubling of the rate of decrease, causes GDP to be substantially higher: 5.7% in 1990 and 14.4% in 2000. GDP in Case 9 is even higher: 6.7% in 1990 and 19.9% in 2000.

IV. LIMITATIONS AND FURTHER IMPROVEMENTS

The base model, as it is presented in this paper, has some limitations that are mostly specific to the mathematical formulation of the model. Limitations will be discussed explicitly in this section, and some suggestions will also be made about how the shortcomings can be overcome. However, the remaining shortcomings of the model will be left for further research.

One major limitation is the fact that the demand for labor is determined through a fixed-coefficients production function and that total demand for labor is constrained by total labor force supply. In the formulation of the demand for labor, the distribution of labor by occupational group and education level is implicitly assumed to be fixed in each productive sector during the planning period. However, this assumption is unrealistic, especially when the economy is undergoing rapid structural change: a shortage of technicians required in certain industries, for example, might constrain other economic variables seriously (see Leibenstein [1965]). If a good count of the number of individuals in different occupation and education levels were available, labor variables could be considered more realistically.

Assume that labor variables, such as WP (graduates entering the labor force), Z (dropouts entering the labor force), E (the level of employment) and L (the number in the labor force) are broken down by education and by occupational group.

Let, $\delta_{i,n,t}$ = the ratio of employment of labor with education level n in sector i to total labor employment in sector i in year t

$\delta_{i,k,t}$ = the ratio of employment of labor from occupation group k in sector i to total employment in sector i in year t

Then the constraint on employment by education and by occupation group can be specified as follows:

(1)′ $E_{n,t} = \Sigma_i \, \delta_{i,n,t} \cdot E^s_{i,t}$

(2)′ $E_{k,t} = \Sigma_i \, \delta_{i,k,t} \cdot E^s_{i,t}$

where $E_{n,t}$ = employment by education level

$E_{k,t}$ = employment by occupational level

$E^s_{i,t}$ = employment by sector i

And

(3)′ $L_{n,t} \geqslant E_{n,t}$

(4)′ $L_{k,t} \geqslant E_{k,t}$

Constraint (3)′ states that the labor force at each education level should be greater than or equal to the number employed from each education level. Constraint (4)′ states that the labor force at each occupation level should be greater than or equal to the number employed from each occupation level. In order to consider the derived demand for labor, the following constraints are specified:

(5)′ $\theta(\Sigma_k WP_{n,k,t} + \Sigma_k Z_{n,k,t}) \geqslant \Sigma_i U_{i,n}(X^s_{i,t} - X^s_{i,t-1})$

where θ = number of years per period

$U_{i,n}$ = the ratio of employment by education level in sector i to gross output by sector i

$X^s_{i,t}$ = sectoral gross output

$WP_{n,k,t}$ = entrants to the labor force after graduation by education and occupational group

$Z_{n,k,t}$ = entrants to the labor force after dropping out by education and occupational group

The left-hand side of constraint (5)′ represents the accumulation of the labor force from each education sector during the planning period. The right-hand side of constraint (5)′ indicates an increasing demand for employment. Thus, constraint (5)′ links the education system to the economic situation.

The limitation of no substitution possibilities in the labor force could be partly overcome if this procedure - which would make use of labor variables disaggregated by occupational group - could be defined in "standard efficiency units." For example, 2 engineers who are junior vocational college graduates may be substituted for 1 engineer who is a university graduate (see Adelman [1966]).

A second major limitation is the fact that a Leontief fixed-proportion production function is sued. The number of graduates by education level is produced by the application of two inputs (teachers and school buildings) which are in fixed proportions. This production function is homogeneous of degree one and thus yields constant returns to scale. The requirement that the number of teachers and school buildings must grow at the same rate as the number of graduates is not a bad assumption. However, substitution between the number of teachers by education level and the quality level attained by various percentages of graduates should be considered in quality-differentiated models (see Kendrick [1974]). In addition, this production function implicitly assumes that there is no possibility of substituting teachers for school buildings in producing graduates. Since an overcrowded school building staffed with excellent teachers might logically be expected to produce as many graduates by education level as a spacious school building staffed only with fair teachers, the underlying fixed-proportion assumption may be unduly restrictive.

A third limitation: the number in the labor force is determined only by the existing labor force minus retirements from the previous period plus the number of graduates and dropouts from the education system in year t. However, the assumption that the effective labor supply in a country is fixed is somewhat strong. As is common in most countries in the process of industrialization, the number of women in the labor force has been increasing markedly. In Korea the labor force participation rate for women has increased from 36.3% in 1963 to 42.2% in 1979 and is expected to continue to rise in the future (see Kim et al. [1981]). When the economy is booming and the demand for labor is increasing, the participation rate for women rises; during economic contraction the participation rate falls. It is therefore desirable to recognize that the participation of women will rise when the economy in need of manpower. Also, it should be possible to permit women's labor supply to increase with increased wages for women who have received enhanced educational opportunities and who have access to an expanded public nursery system. Thus, using the labor participation rate and total population as variables would overcome the fixed labor supply limitation (see Alatorre [1981]).

A fourth limitation: the levels of sectoral private consumption demand are determined by a fixed basket of total private consumption. This specification has the advantage that undesirable fluctuations in consumption paths are avoided. However, this may make it difficult to investigate how consumption behavior affects other economic variables. Clearly a more dynamic consumption formula would improve predictions made using different policies. In order to overcome this difficulty at least partially, a first order expansion for sectoral private consumption can be used as follows:

$$CP_{i,t} = (1-\varepsilon_i)\cdot CP_{i,1985}\cdot(POP_t/POP_{1985}) + \varepsilon_i\cdot(CP_{i,1985}/CP_{1985})\cdot CP_t$$

where ε_i = Engel elasticity

POP_{1985} = population in the base year

POP_t = population in year t

CP_t = total private consumption demand in year t

$CP_{i,t}$ = sectoral private consumption demand in year t

Here, the Engel elasticities must satisfy the condition

$$\Sigma_i\ \varepsilon_i\cdot(CP_{i,1985}/CP_{1985}) = 1$$

from consumer demand theory (see Henderson and Quandt [1971]). While Engel elasticities are of ten taken from cross-section budget studies and modified to satisfy the above condition, there are some problems in "transferring this type of cross-section estimate to time series projections" (see Taylor [1975]). Alternatively, Engel elasiticities can be estimated from time series. The national accounts provide data on consumption levels, such as food and rent. According to Taylor [1975], these are not the same as input-output classification categories, so time series elasticities can provide only indirect evidence about the ε_i (Engel elasticity).

A fifth limitation: all of the economic variables, including export and import variables, are expressed in 1980 prices. As a country poorly endowed with natural resources, Korea's trade dependency is projected to increase considerably during the coming 10 years. If so, it clearly would be expected that the volume of foreign trade and overall domestic economic activity would be affected by price increases of foreign natural resources, especially crude oil. A price hike for certain import goods would worsen the balance of payments. Consequently, domestic production activities could be constrained by restricted supplies of some import goods. In order to investigate the effects on economic variables from such an external shock in the long-term projection model, the equations for foreign trade and balance of payments could be expressed in current prices (see Kim [1981]).

REFERENCES

ADELMAN, IRMA (1966), "A linear programming model of educational planning: A case study of Argentina." in Irma Adelman and E. Thorbecke (Eds.) *The Theory and Design of Economic Development.* Baltimore: Johns Hopkins Press.

ADELMAN, IRMA, DAVID C. COLE, ROGER NORTON, and LEE KEE JUNG (1969), "The Korean Sectoral Model." in Irma Adelman (Ed.) *Practical Approaches to Development Planning: Korea's Second Five-Year Plan.* Baltimore: The Johns Hopkins University Press.

ALATORRE, JAIME E. (1981), *A Long-Term Planning Model for Mexico.* Center for Economic Research, Department of Economics, University of Texas at Austin.

BECKER, GARY S. (1964), *Human Capital.* Chicago: The University of Chicago Press.

BOWLES, SAMUEL (1967), "The Efficient Allocation of Resources in Education." *Quarterly Journal of Economics* 81.

BLITZER, CHARLES R. (1975), "Employment and Human Capital Formation." in Charles R. Blitzer, Peter B. Clark, and Lance Taylor (Eds.) *Economy-Wide Models and Development Planning.* London: Oxford University Press.

BROOKE, ANTHONY, DAVID KENDRICK, and ALEXANDER MEERAUS (1988), *GAMS: A User's Guide.* Redwood City: The Scientific Press.

CHAKRAVARTY, SUKHAMOY, and LOUIS LEFEBER (1965), "An Optimizing Planning Model." *The Economic Weekly,* Vol. 17, No. 5-7.

CHARNES, A., M.J.L. KIRBY, and A.S. WALTERS (1970), "Horizon Models for Social Development." *Management Science,* Vol. 17, No. 4.

CLARK, PETER B., and LANCE TAYLOR (1971), "Dynamic input-output planning with optimal end conditions: The case of Chile." *Economics of Plannings,* Vol. 11, No. 1-2.

COHN, ELCHANAN (1972), *The Economics of Education.* Lexington: D.C. Heath and Company.

DENISON, E.F. (1962), *The Sources of Economic Growth in the United States and the Alternatives before us.* New York: The Brookings Institute.

DORFMAN, ROBERT, PAUL A. SAMUELSON, and ROBERT M. SOLOW (1958). *Linear Programming and Economic Analysis.* New York: McGraw-Hill Book Company.

ECONOMIC PLANNING BOARD (Annual Issues 1979-1986), *Korea Statistical Yearbook.*

Seoul, Korea.

GINSBURGH, VICTOR A., and JEAN L. WAELBROECK (1981), *Activity Analysis and General Equilibrium Modeling.* Amsterdam: North-Holland Publishing Company.

GOREUX, LOUIS M., and ALAN S. MANNE (Eds.) (1973), *Multi-Level Planning: Case Studies in Mexico.* New York: North-Holland/ American Elsevier Publishing Company.

HADLEY, G. (1962), *Linear Programming.* Reading, Massachusetts: Addison-Wesley.

HARBERGER, A.C. (1965), "Investment in man versus investment in machines: The case of India." in C.A. Anderson and M.J. Bowman (Eds.) *Education and Economic Development.* Chicago: Aldine Publishing Company.

HENDERSON, JAMES M. and RICHARD E. QUANDT (1971), *Microeconomic Theory: A Mathematical Approach.* New York: McGraw-Hill Book Company.

HUTCHISON, MICHAEL (1987), "Korea and Export-Led Growth." *FRBSF Weekly Letter,* December 4, 1987.

INMAN, RICHARD A., ROGER D. NORTON, YOON—HYUNG KIM (1979), "A Multi-Sectoral Model with Endogenous Terminal Conditions." *Journal of Development Economics* 6.

JORGENSON DALE W. (1961), "The Structure of Multi-Sector Dynamic Models." *International Economic Review* 2.

KENDRICK, DAVID A. (1974), *Mathematical Methods in Economic Planning,* Ch. 8. Educational Planning Models. Mimeographed, Department of Economics, University of Texas at Austin.

KENDRICK, DAVID A., and LANCE TAYLOR (1970), "Numerical Solution of Nonlinear Planning Models." *Econometrica* 38.

KENDRICK, DAVID A., and ARDY J. STOUTJESDIJK (1978), *The Planning of Industrial Investment Programs, A Methodology.* Baltimore: The Johns Hopkins University Press.

KENDRICK, DAVID A., ALEXANDER MEERAUS, and JAIME E. ALATORRE (1984), *The Planning of Investment Programs in the Steel Industry.* Baltimore: The Johns Hopkins University Press.

KIM, KYU-SOO (1981), "Seonhyung-kyehoek-mohyung-e euihan Kyungje-yecheuk gwa Jeongchaek-Simulation." *Hankook Kaebal yonkoo* 3:2. Seoul: Korea.

KIM, MYUNG-SOOK (1985), "Jibang-kyoyook-jaejeong-eui Jeongchaek-kwaje-wa Kaeseon-banghyang." in Kye-Shik Lee, and Tae-Won Kwak (Eds.) *Kukkayehsan-kwa Jeongchaek-mokpyo.* Seoul: Korea.

KIM, YOON-HYUNG (1977), "A 53-Sector Interindustry Projection Model, 1974-1981." in Chuk-Kyo Kim (Ed.) *Planning Model and Macroeconomic Policy Issues.* Seoul: Korea Development Institute.

Korea Development Institute (1978), *Long-Term Prospect for Economic and Social Development: 1977-1991.* Seoul.

Korea Development Institute (1985), *2000 Nyun-eul hyanghan Kookka-janggi-baljeonkoosang: Tchongwal-bogoseo.* Seoul.

Korea Institute for Population and Health (1985), *2000 Nyun-eul hyanghan Kookkajanggi-baljeon-koosang: Inkoo-mit Bokeon-euiryo-boomoon.* Seoul.

Korean Educational Development Institute (1986), *2000 Nyun-eul hyanghan Kokkajanggi-baljeon-koosang: Kyoyook-boomoon.* Seoul.

KORNAI, J. (1969), "Multi-Level Programming- A First report on the Model and on the experimental Computations." *European Economic Review* 1, No. 1.

LAGANA, ANTONIO B. y MAURICIO M. GALAN (1985), *Un Modelo Multisectorial de Planeacion del Sistema Educativo, Oferta de Mano de Obra y la Economia Global: Una Aplication a Mexico.* Facultad de Contaduria y Administracion. Universidad Nacional Autonoma de Mexico, Mexico D.F.

LAGANA, ANTONIO B., and MAURICIO M. GALAN (1987), *An Optimizing Model of Labor Needs, Labor Supply, and Economic Planning.* Discussion Paper 87-1. Center for Economic Research, Department of Economics, University of Texas at Austin.

LEIBENSTEIN, HARVEY (1965), "Shortages and Surpluses in Education in Underdeveloped Countries." in C. Arnold Anderson and Mary Jean Bowman (Eds.) Education and Economic Development. Chicago: Aldine Publishing Company.

MANNE, ALAN S. (1973), "DINAMICO, a Dynamic Multi-sector, Multi-skill Model." in Louis M. Goreux, and Alan S. Manne (Eds.) *Multi-Level Planning: Case Studies in Mexico.* New York: North-Holland/American Elsevier Publishing Company.

MCGINN, NOEL F., D.R. SNODGRASS, Y.B. KIM, and Q.Y. KIM (1980), *Education and Development in Korea.* Harvard East Asian monographs 90. Cambridge: Harvard University Press.

MILLER, RONALD E., and PETER D. BLAIR (1985), *INPUT-OUTPUT ANALYSIS: Foundations and Extensions.* Englewood Cliffs: Prentice-Hall, Inc..

OFFICE of the PRIME MINISTER (1980), *Evaluation Report of the Third Year Program: The Fourth Five-Year Economic Development Plan.* Seoul.

PARNES, HERBERT, S. (1962), *Forecasting Educational Needs for Economic and Social Development.* Paris: Organization for Economic Co-operation and Development.

SCHULTZ, THEODORE W. (1963), *The Economic Value of Education.* New York: Columbia University Press.

SCHULTZ, THEODORE W. (1971), *Investment in Human Capital: The Role of Education and of Research.* New York: The Free Press.

SEN, AMARTYA K. (1970), "Models of Educational Planning and Their Applications." *Journal of Development Planning* 2: United Nations (ST/ECA/129). New York.

STONE, RICHARD A., JOHN BATES, and MICHAEL BACHARACH (1963), Input-Output Relationships, 1954-1966, Vol. 3 in *A Programme for Growth.* London: Chapman and Hall.

The Bank of Korea (1975, 1978, 1980, 1983, 1985), *Input-Output Tables.* Seoul.

The Bank of Korea (1981-1986), *Economic Statistics Yearbook.* Seoul.

The Bank of Korea (1987), *1970-1986 National Accounts.* Seoul.

The Ministry of Education (Annual Issues 1968-1986), *Statistical yearbook of Education.* Seoul.

TINBERGEN, JAN, and H.C. BOS (1965), "A Planning Model for The Educational Requirements of Economic Development." in *Econometric Models of Education.* Paris: Organisation for Economic Co-operation and Development.

URIBE, PEDRO (1975), "Some RAS Experiments with the Mexican Input-Output Model." *Annals of Economic and Social Measurement,* Vol. 4, No. 4.

WATANABE, TSUNHIKO (1975), "Quantitative Foundations and Implications of Planning Processes." in Charles R. Blitzer, Peter B. Clark, and Lance Taylor (Eds.),

Economy-Wide Models and Development Planning. London: Oxford University Press.
WESTPHAL, LARRY E. (1971), *Planning Investments with Economies of Scale*. Amsterdam: North-Holland Publishing Company.