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Long Run Behavior of R&D Investment and Economic Growth : A Macro-econometric Model

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Introduction

- Motivation
 - To show relationship between R&D activity and major macro-economic variables. Most studies investigate a single production function only.
 - To provide a reference for the discussion about sustainability of Korean economy in transition from resourced-based growth strategy to innovation-based growth strategy.

- We established a macro-econometric model including R&D sector.
 - A simultaneous equation system : small model (49 equations and identities).
 - Recalculation of the national accounts was necessary to avoid double counting.

- After estimation of the model, we carried out a simulation analysis for alternative policy measures, such as R&D investment, construction investment, investment fund for SMEs, and unemployment fund.
 - To Measure direct and indirect effect of R&D on the major economic variables.
 - To make a comparison of effects of alternative policy instruments.



R&D Stock : Data and national accounting

Data

- From the national accounting, we have

$$GDP = C + I + G + (X - M) + RD$$

- R&D investment consists of private R&D (RD_P) and public R&D (RD_G). It also consists of consumption expenditure and purchase of R&D capital. The consumption expenditure includes private and government expenditures. The R&D capital is divided into equipments (RD^Q) and buildings (RD^H)
- That is,

$$RD = RD_P + RD_G$$

$$RD = RD^C + RD^K$$

$$RD^C = RD_P^C + RD_G^C$$

$$RD^K = RD^Q + RD^H$$

P \equiv private

G \equiv government

C \equiv consumption expenditure

K \equiv R&D capital

Q \equiv equipments

H \equiv buildings



R&D Stock : Data and national accounting

- Then, we recalculate the national accounts and separate out the R&D sector of the national economy.

$$GDP = (C - RD_P^C) + (I - RD^K) + RD + (G - RD_G) + (X - M)$$

- Therefore, we can divide the national economy into R&D sector and non-R&D sector from the above equation.
- Note that R_G is not broken down into consumption expenditure and R&D capital purchase. It is taken account as consumption expenditure.



R&D Stock : Estimation

Assumptions

- R&D lags
 - Private R&D : 2 years
 - Public R&D : 3 years
- Rate of knowledge obsolescence : 0.125 (8 years)

$$RDSK_t = RD_{t-l} + (1 - \delta)RDSK_{t-1} ,$$

l = 2 for public R & D; l = 3 for private R & D

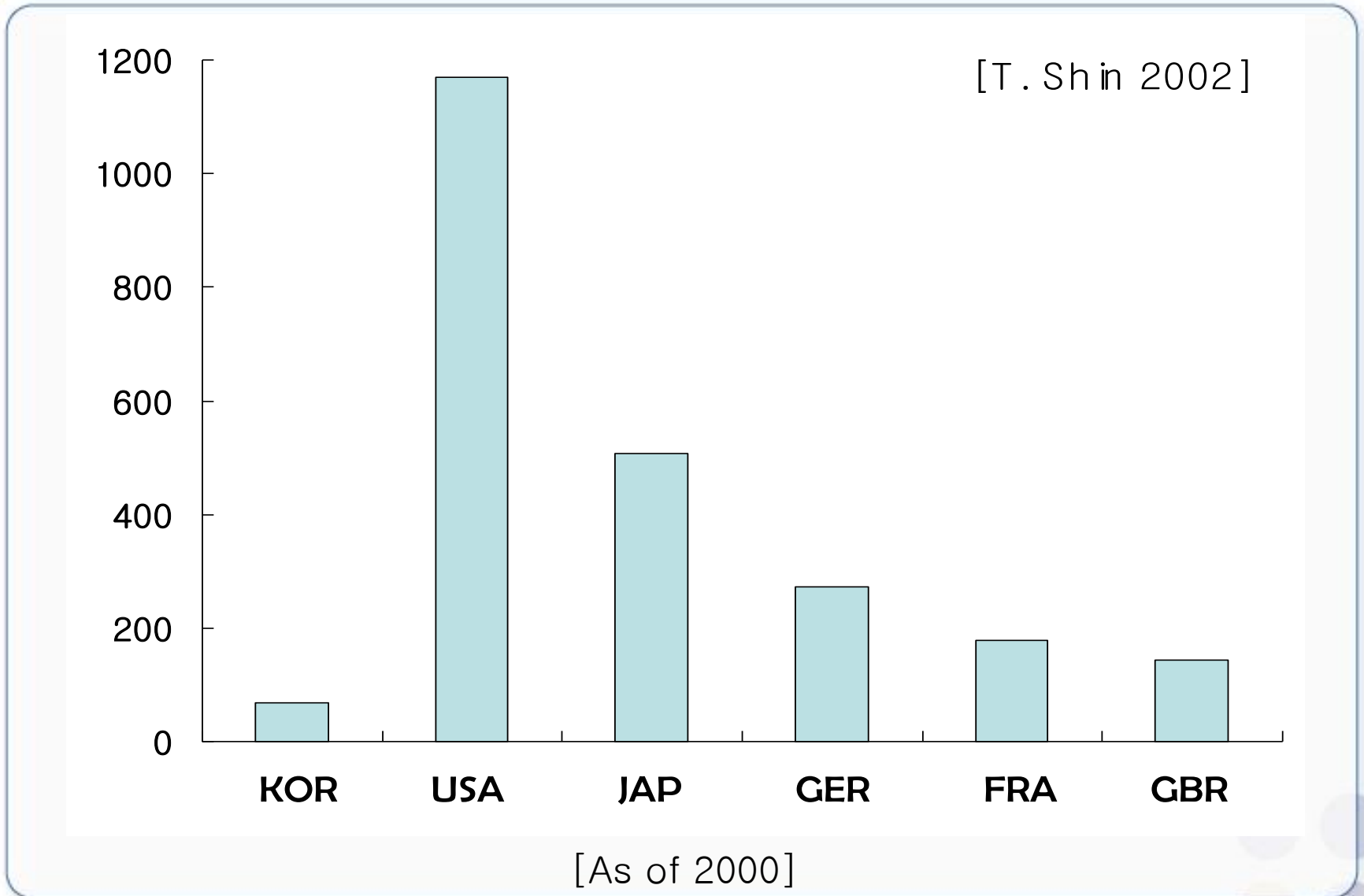
$$RDSK_0 = \sum_{i=0}^{\infty} RD_{t_0-i} (1 - \delta)^i \Rightarrow RDSK_0 = RD_{t_0} \left[\frac{1 + g}{g + \delta} \right]$$

$g \equiv$ growth rate of R&D stock

$\delta \equiv$ rate of knowledge obsolescence



R&D Stock : An international comparison





Potential GDP : Production function

Production function

$$Y_t = A(R_t) f(K_t, L_t)$$

$$\Rightarrow \log Y_t = \beta_0 + \beta_1 \log K_t + (1 - \beta_1) \log L_t + \beta_2 \log RDSK_t + \varepsilon_t$$

Y \equiv GDP
K \equiv capital stock
L \equiv labor
RDSK \equiv R&D stock

$$\log Y_t = -5.852 + 0.3043 \log K_t + (1 - 0.3043) \log L_t + 0.2097 \log RDSK_t$$

(-24.98) (4.829) (5.678)

$$R^2 = 0.997, \quad D.W. = 0.409$$

Potential GDP : Natural rate of unemployment

- Natural rate of unemployment : rate of unemployment without accelerating inflation
 - The price equation was estimated as follows.

$$\dot{P}_t = 10.803 - 4.242U_t - 0.053\dot{U}_t + 0.300\dot{P}_{M_t}$$
$$(2.663)(-3.415) \quad (-0.667) \quad (3.045)$$

- Then, the natural rate of unemployment is

$$U^N = 2.547 (=10.803/4.242)$$

- The number of the employed at the natural rate of unemployment will be

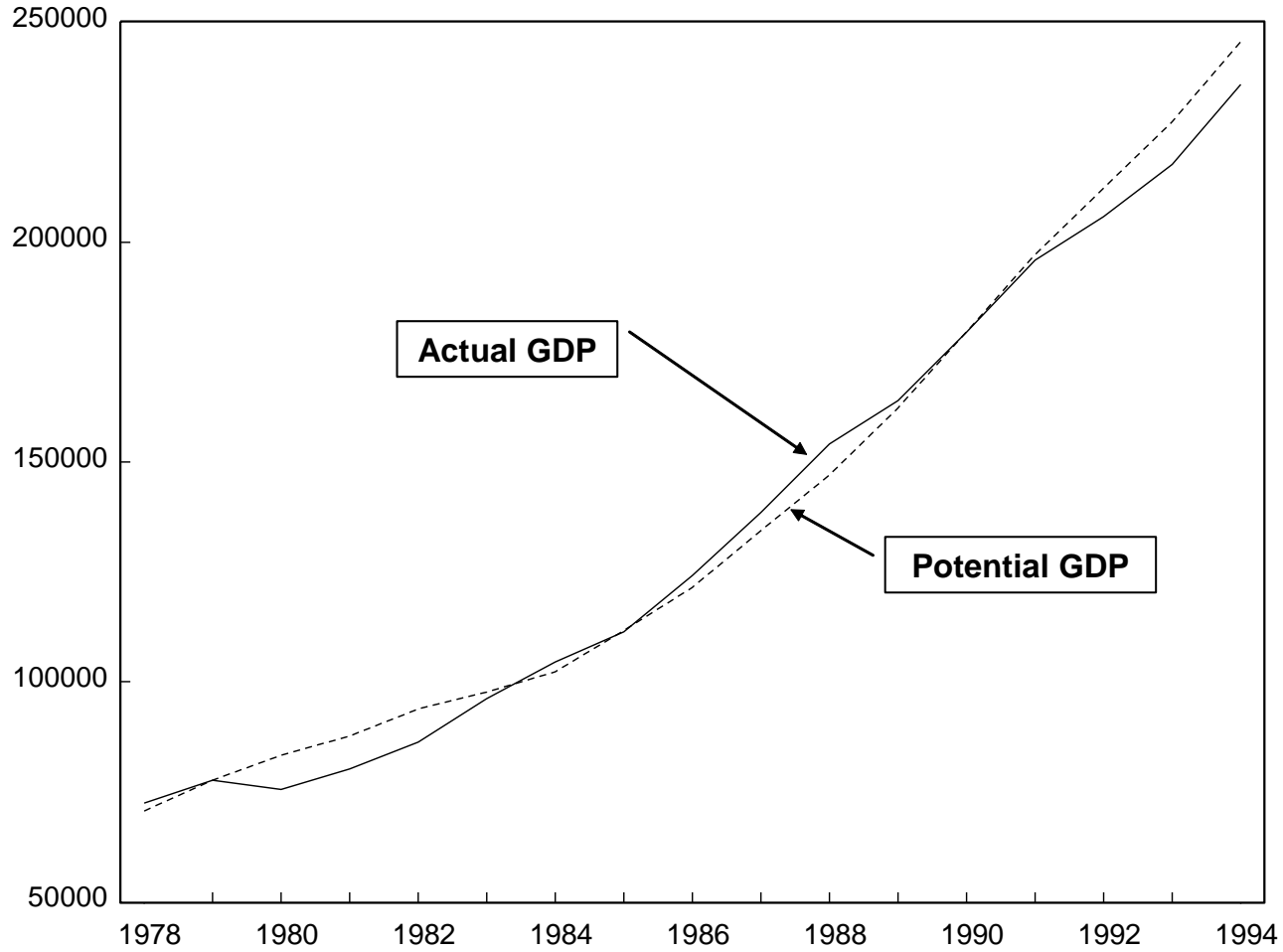
$$L^N = (LF - L_{RD}) - (U^N \times LF / 100)$$

- The potential GDP can be obtained plugging L^N into the production function.

U ≡ rate of unemployment
P_M ≡ import prices
LF ≡ labor force



Potential GDP and real GDP





Model : Structure

- The model includes 6 sectors and exogenous variables
 - Demand side and prices
 - Supply side
 - Wage and employment
 - Foreign trade
 - Monetary sector
 - Public finance.

- The model consists of 27 behavioral equations and 22 identities.



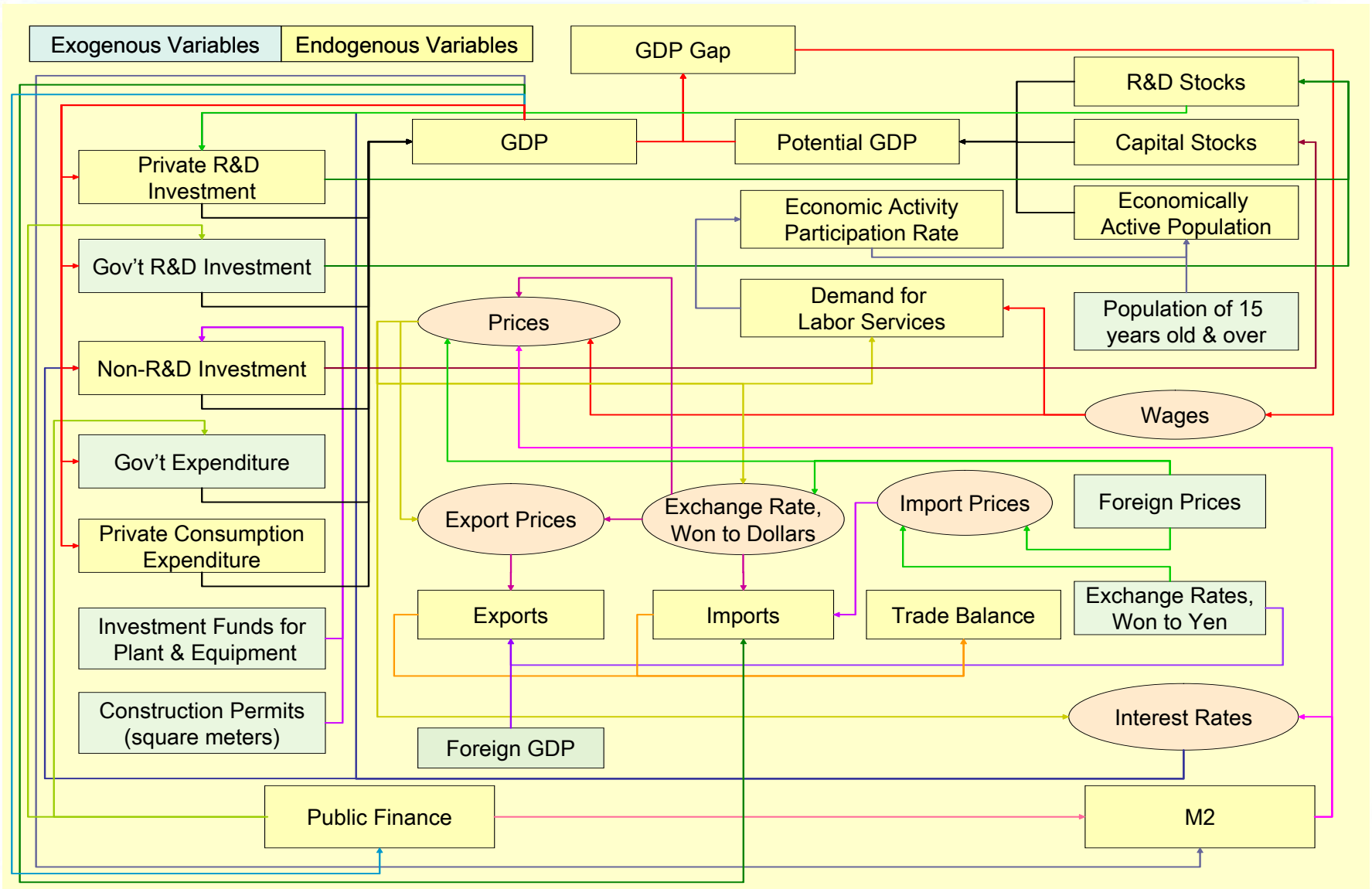
Model : Adjustment mechanism

- The model is established in the way that the interaction of real GDP and potential GDP (GDP gap) makes self-adjustment of the economy toward an equilibrium.
 - If there is a change in GDP gap by a shock, the economy will leave an equilibrium and starts to adjust; and to move toward a new equilibrium. The shock is conveyed through the price variables to other sectors.

- For example, if government increases R&D spending,
 - Firstly, real GDP \uparrow \rightarrow GDP gap (excess demand) \uparrow \rightarrow wage \uparrow \rightarrow price \uparrow \dots
 $\rightarrow \dots$ new equilibrium.
 - Secondly, in time R&D stocks \uparrow \rightarrow potential GDP \uparrow \rightarrow GDP gap \downarrow \rightarrow wage \downarrow
 $\dots \rightarrow \dots$ new equilibrium.
 - This can be shown in the flow chart below.



Model : Flow chart



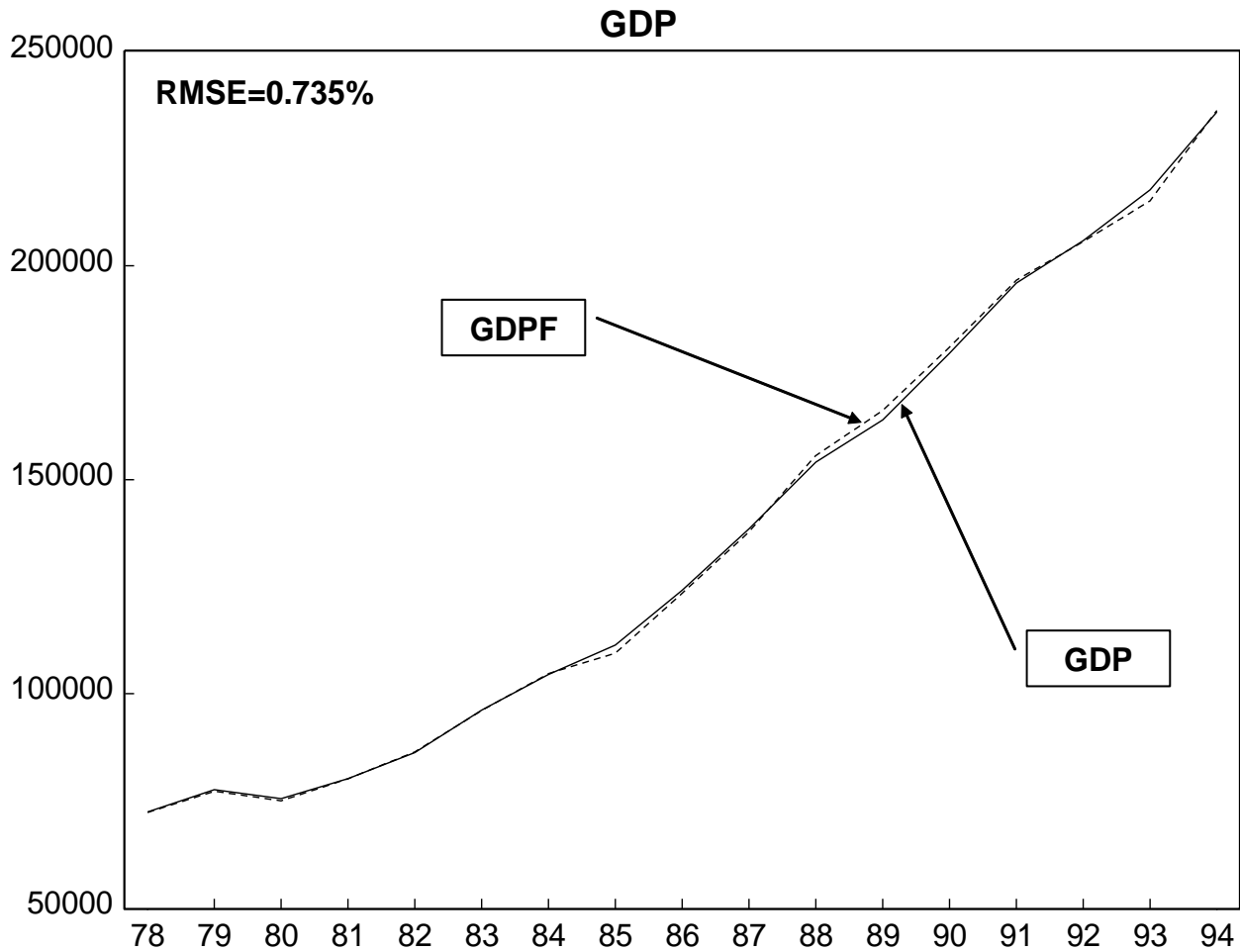


Model : Goodness of fit

Variables	RMSE (%)	Variables	RMSE (%)
DEMAND SIDE AND PRICES	2.086	FOREIGN TRADE	2.31
<i>GDP</i>	0.735	<i>EXCB</i> : commodity exports	2.734
<i>CPVRD</i> : private consumption of non-R&D Sector	0.504	<i>IMCB</i> : commodity imports	0.979
<i>KIHRD</i> : construction investment of non-R&D sector	1.383	<i>EXSNB</i> : non-factor income from abroad	5.16
<i>KIQRD</i> : plant/equipment investment of non-R&D sector	3.538	<i>IMSNB</i> : non-factor income to abroad	3.523
<i>RDIPV</i> : private R&D investment	4.865	<i>PX</i> : export price index	1.342
<i>PGDP</i> : GDP deflator	2.102	<i>PM</i> import price index	1.45
<i>CPI</i> : consumer price index	1.498	<i>ER</i> : exchange rates	0.981
<i>WPI</i> : producer's price index	2.061		
		MONETARY SECTOR	2.816
SUPPLY SIDE	0.483	<i>RM2</i> : real M2	1.305
<i>PTGDP</i> : potential GDP	0.483	<i>RCB</i> : yields of corporate bonds	4.327
WAGES AND EMPLOYMENT	1.596	PUBLIC FINANCE	3.189
<i>LFPR</i> : participation rate in economic activities	0.558	<i>TXR</i> : tax revenues	3.714
<i>EMPD</i> : number of the employed in non-R&D sector	0.704	<i>CGE</i> : expenditures of central government	2.663
<i>RD MN</i> : number of researchers	1.859		
<i>RWG</i> : monthly real wage of workers in MFG.	0.854	TOTAL	2.133
<i>RDWG</i> : annual R&D personnel expenses per researcher	4.003		

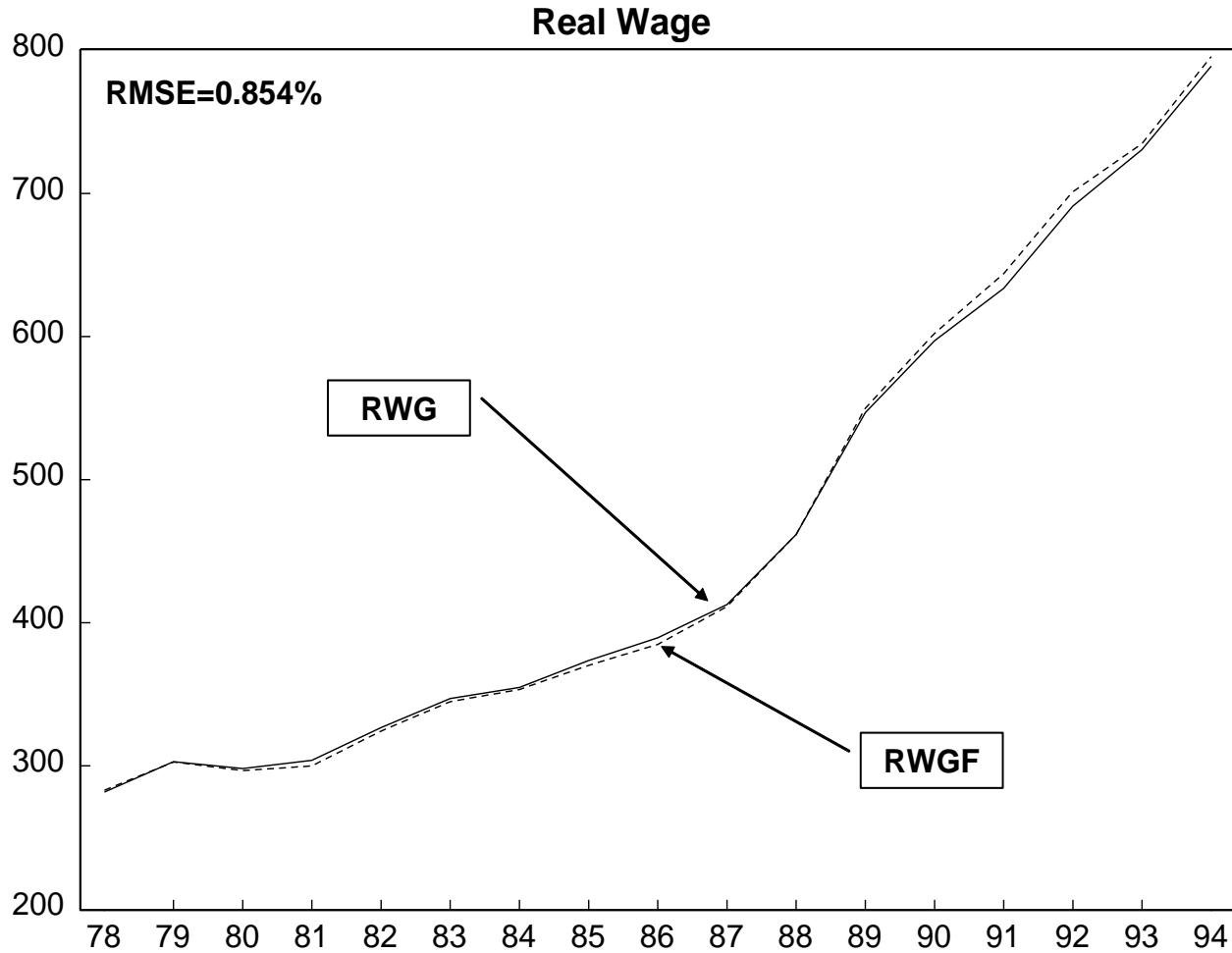


Goodness of Fit : GDP



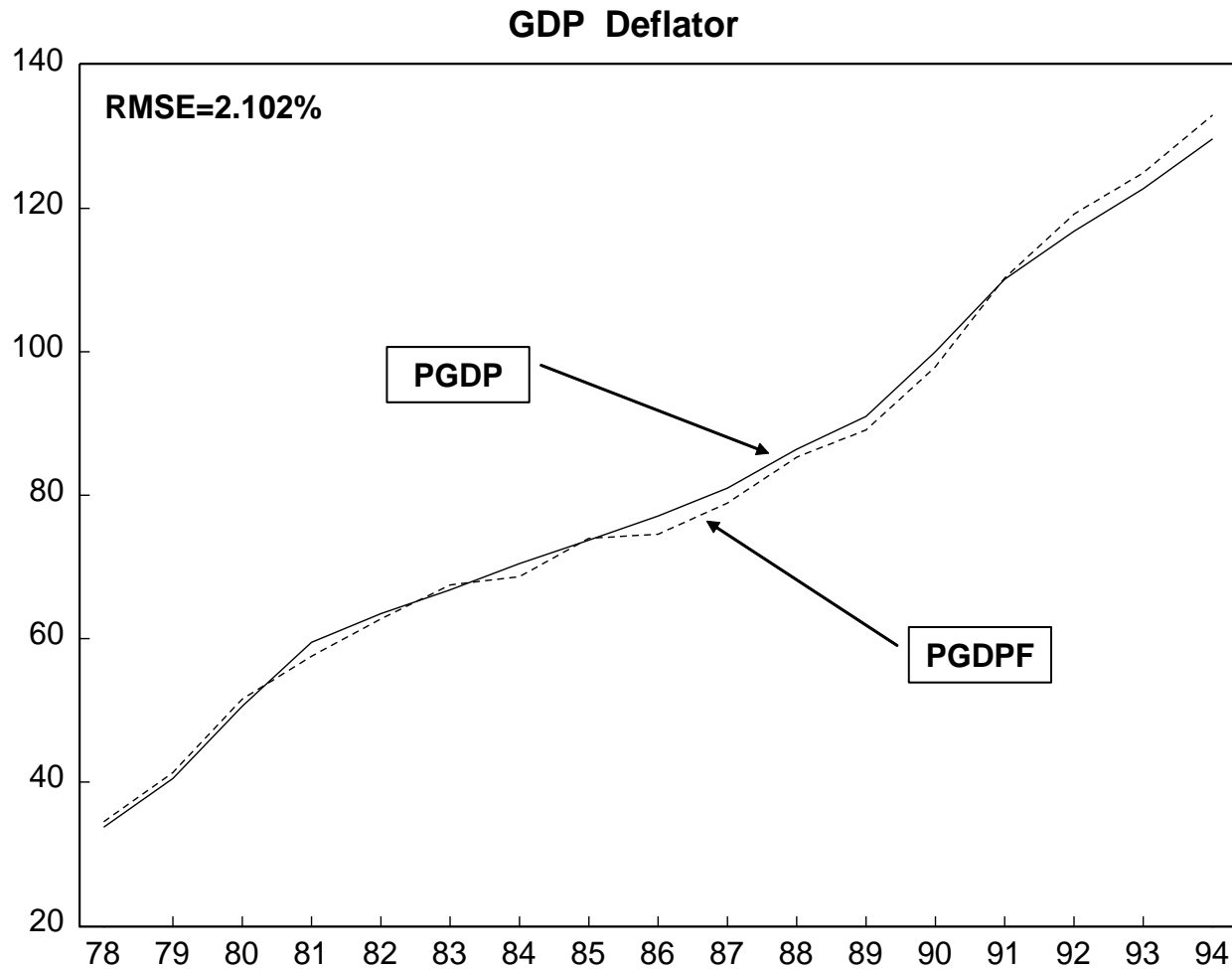


Goodness of Fit : Real wage





Goodness of Fit : GDP deflator





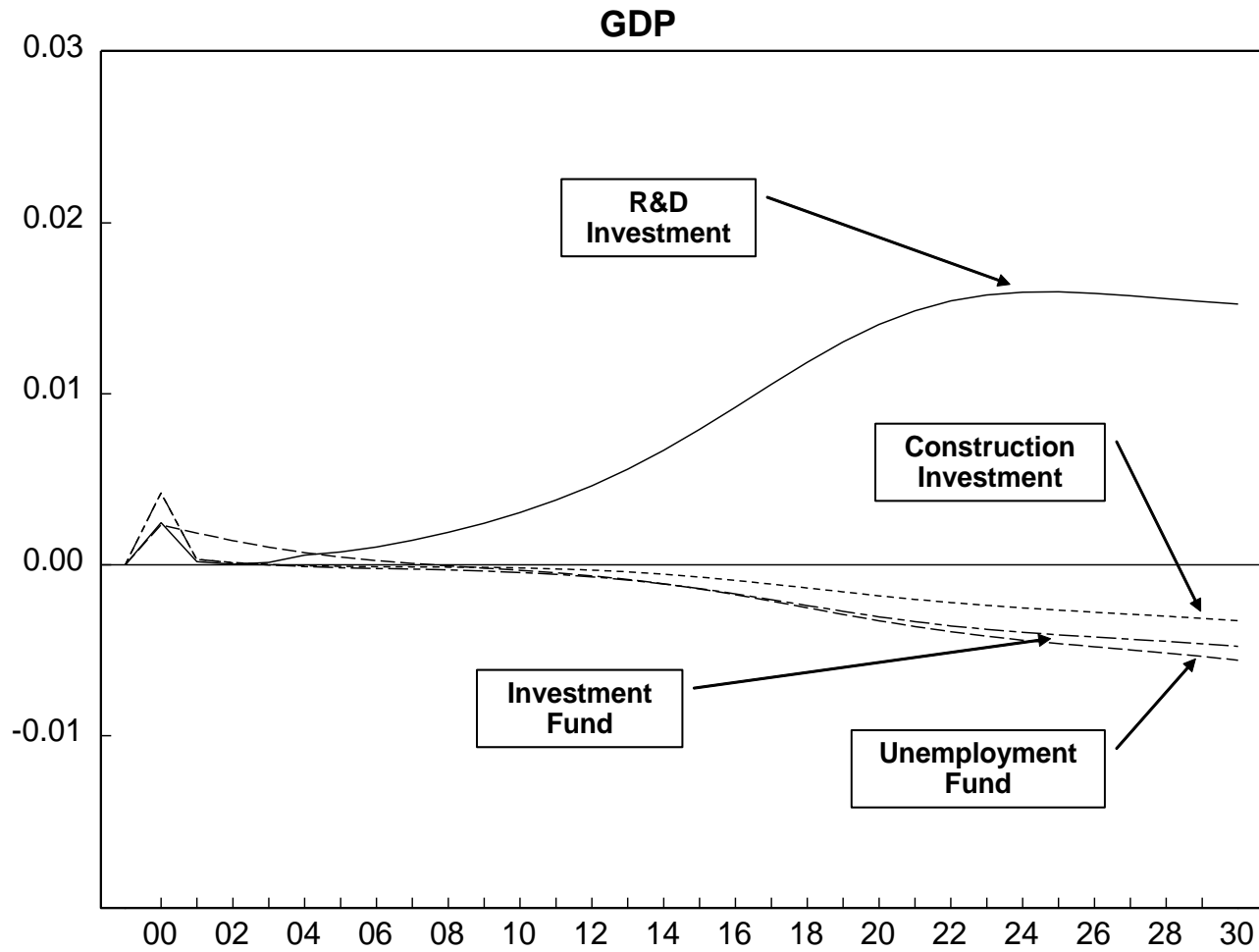
Simulation results

After	GDP (%)				Unemployment Rate (% point)			
	R&D investment	Construction investment	Investment fund	Unemployment fund	R&D investment	Construction investment	Investment fund	Unemployment fund
One year	0.250	0.420	0.230	0.420	-0.052	-0.044	-0.025	-0.048
5 years	0.060	-0.010	0.070	-0.010	0.029	0.004	-0.004	0.005
10 years	0.240	-0.020	-0.020	-0.040	-0.037	0.003	0.006	0.008
15 years	0.670	-0.060	-0.110	-0.110	-0.085	0.005	0.012	0.013
20 years	1.300	-0.160	-0.290	-0.270	-0.130	0.014	0.026	0.025
25 years	1.590	-0.250	-0.440	-0.400	-0.136	0.021	0.037	0.033
30 years	1.540	-0.310	-0.540	-0.460	-0.104	0.022	0.037	0.032

Note : Numbers are cumulative effects when the government increases the spending of one trillion KRW by deficit financing.

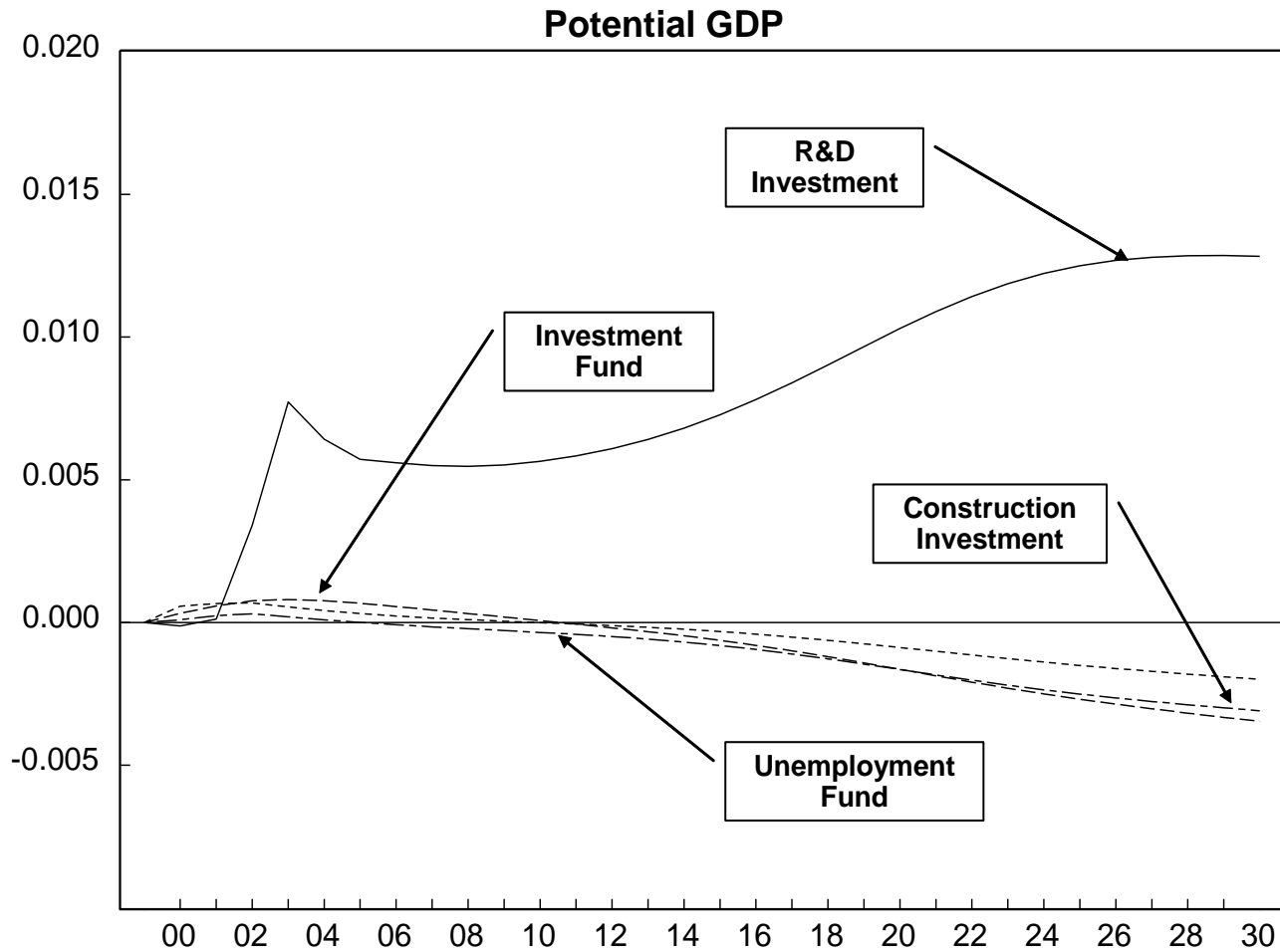


Simulation Results : GDP



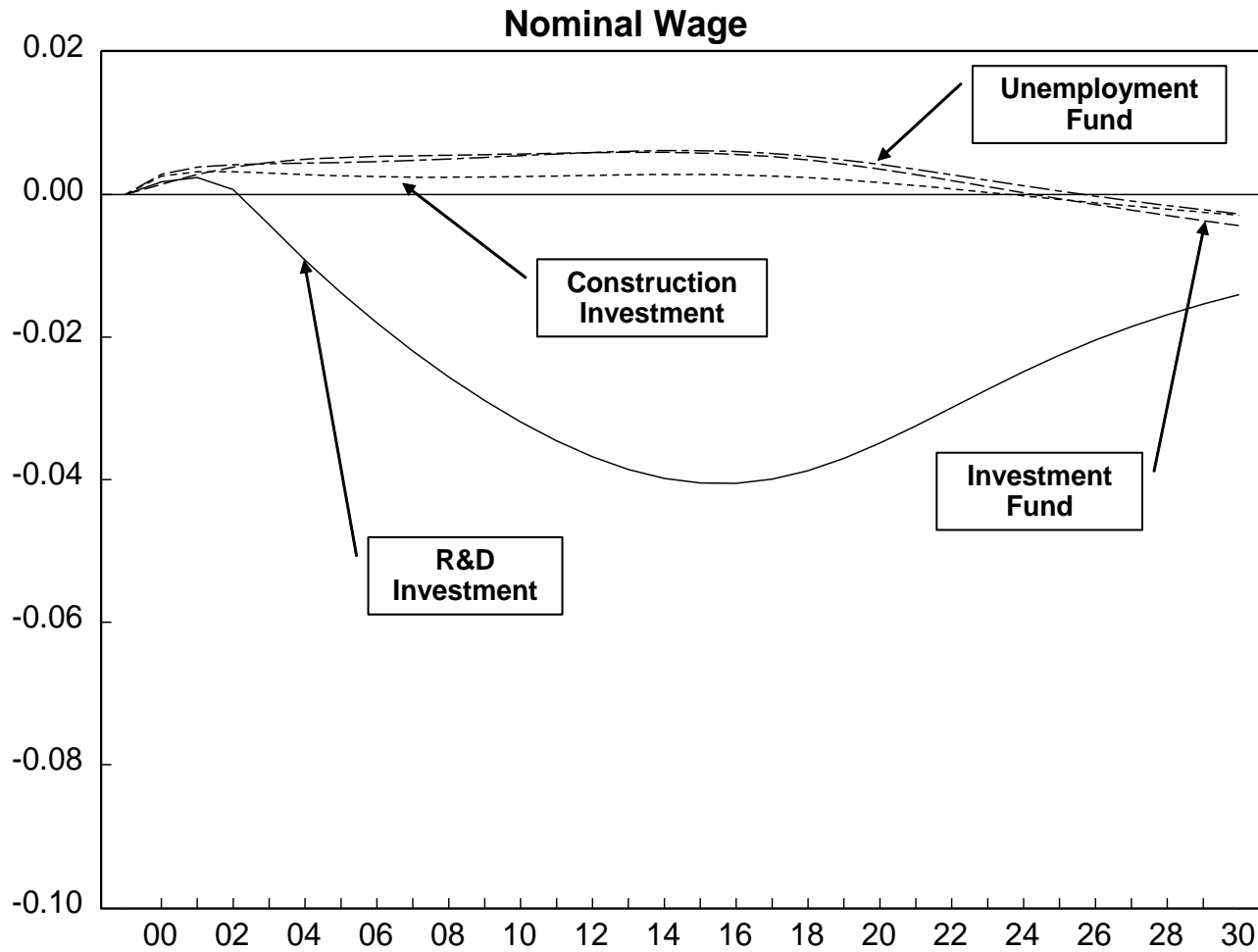


Simulation Results : Potential GDP



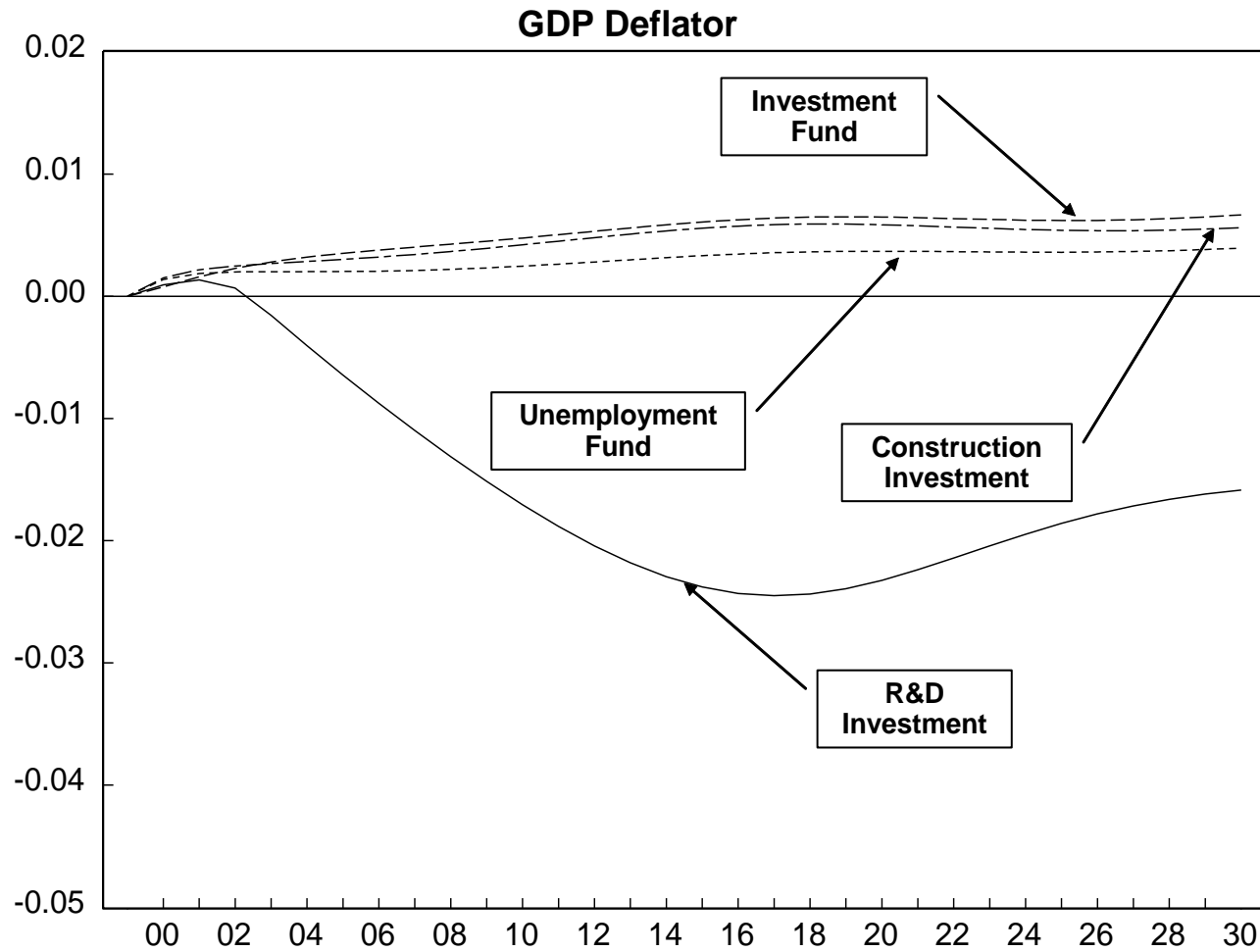


Simulation Results : Nominal wage



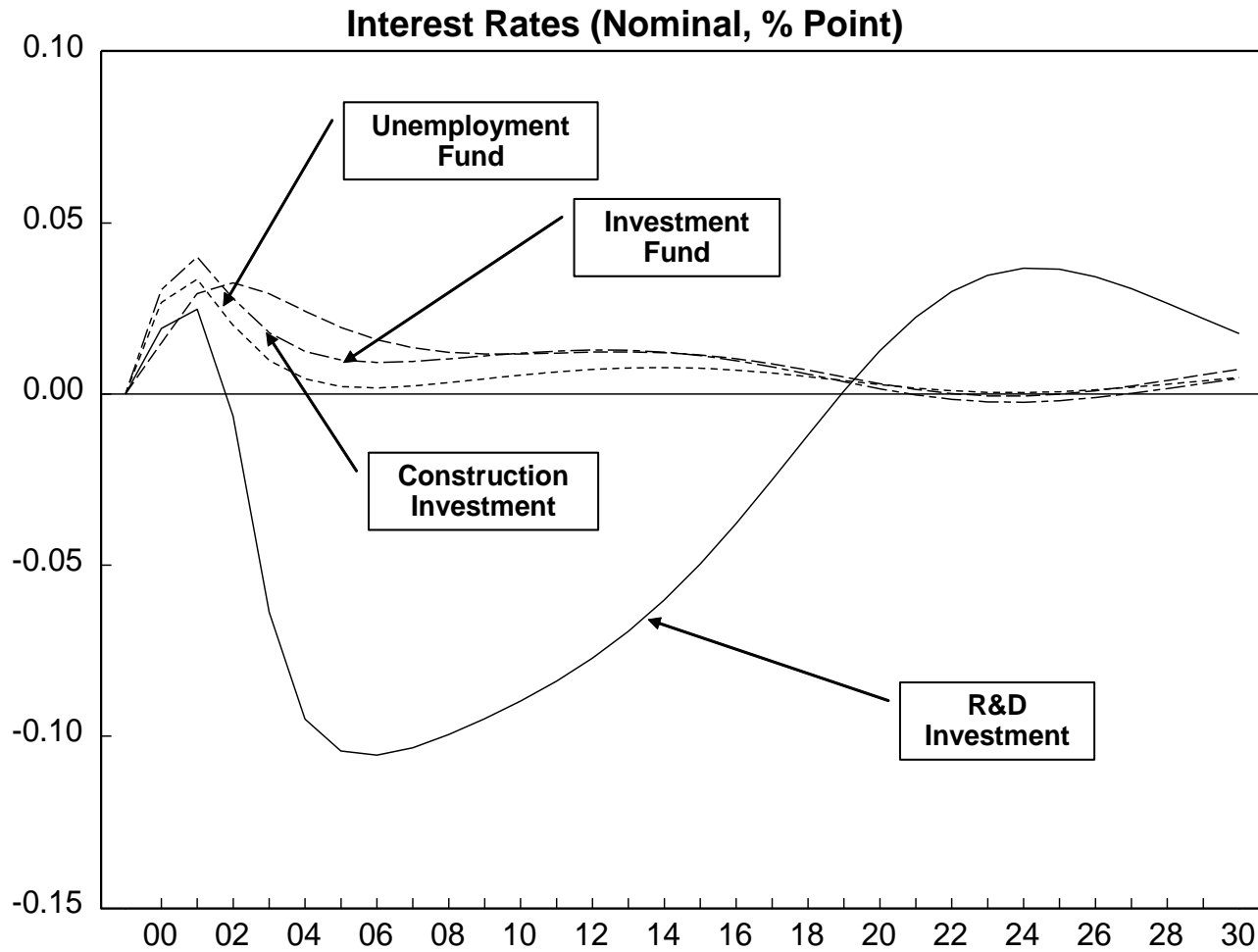


Simulation : GDP deflator



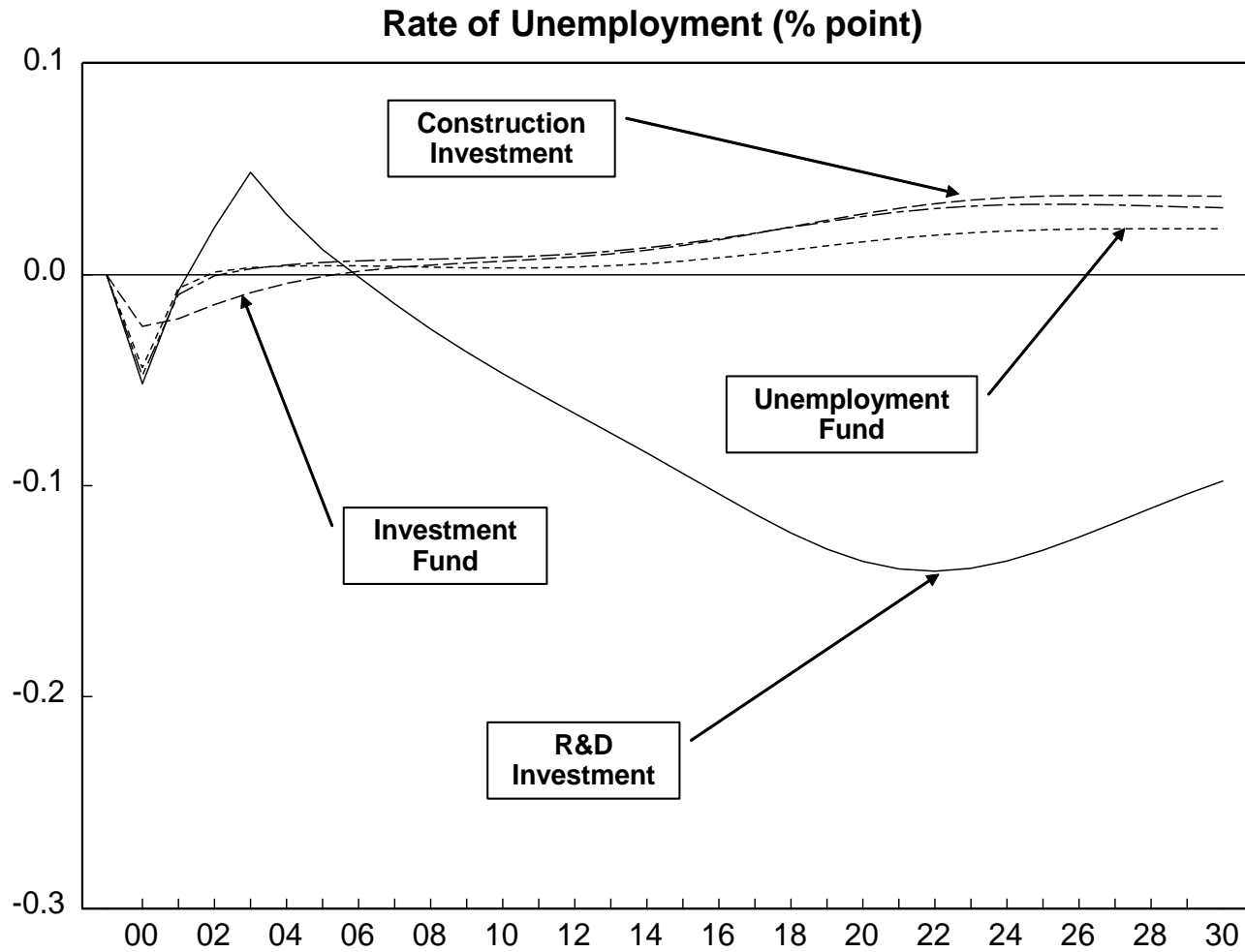


Simulation Results : Nominal interest rate





Simulation Results : Rate of unemployment





Limitation of Model

- In estimating R&D stocks, some assumptions were required
 - Lag structure
 - Rate of knowledge obsolescence

- Data
 - Sample size : sample period 1975~1994
 - R&D data

- Other econometric considerations
 - Data stability : Unit root and cointegration



Concluding Remarks

- The macro-econometric model is a useful scheme to show how R&D activity is related to the national economy.
 - Real variables
 - Price variables

- The simulation results show that
 - Public spending on R&D might have a permanent effect on real variables, with stabilizing price variables.
 - Public spending on other policy alternatives exhibit only short-run effect on real variables, with having positive effect on prices in the long run.

- The government policy might need to focus more on R&D in the long run for the sustainable economic growth.
 - Switching growth strategy from resourced-based to Innovation-based growth.
 - Increasing R&D investment is important—particularly stimulating private R&D by the policy instrument.



Appendix A : Model structure

Demand side and prices

Dependent Variables		Independent Variables							
		Demand/ Prices		Supply Side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance	Exogenous Variables
Behavioral Equations	CPVRD	GDP	CPVRD					TXR	
	KIHRD	GDP							BCP
	KIQRD	GDP INFR	PGDP	KSQRD			RCB		
	RDIPV	GDP INFR		RDSTK			RCB		RDIPB
	PGDP	PGDP			WGE	ER	M2		PM
	CPI	PGDP	CPI						
	WPI	PGDP	WPI			ER			PM
	INFR	PGDP							
Identities	GDP	CRD KIRD RDI	EX IM SDI						
	CRD	CPVRD	CPBRD						
	KIRD	KIHRD KIQRD	KINV						
	RDI	RDIPV	RDIPB						
	EX	EXC	EXSN						
	EXC					EXCB			
	EXSN					EXSNB			
	IM	IMC	IMSN						
IMSN					IMCB				



Appendix A : Model structure

Supply side

Dependent Variables		Independent Variables					
		Demand/ Prices	Supply side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance
Behavioral Equations	<i>PTGDP</i>		<i>KSKRD</i> <i>RDSTK</i>	<i>EMPDN</i>			<i>MORIB</i> <i>YDAYB</i>
	<i>EMPN</i>			<i>LF</i> <i>RDMN</i>			<i>URSTR</i>
Identities	<i>KSTRD</i>		<i>KSHRD</i> <i>KSQRD</i>				
	<i>KSHRD</i>	<i>KIHRD</i>	<i>KSHRD</i>				
	<i>KSQRD</i>	<i>KIQRD</i>	<i>KSQRD</i>				
	<i>RDSTK</i>		<i>RDKPV</i> <i>RDKPB</i>				
	<i>RDKPV</i>	<i>RDIPV</i>	<i>RDKPV</i>				
	<i>RDKPB</i>	<i>RDIPB</i>	<i>RDKPB</i>				



Appendix A : Model structure

Wage and employment

Dependent Variables		Independent Variables						
		Demand/ Prices	Supply Side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance	Exogenous Variables
Behavioral Equations	<i>LFPR</i>	<i>GDP</i>	<i>PTGDP</i>	<i>EMPL</i> <i>LFPR</i>				<i>POP15</i>
	<i>EMPD</i>	<i>CPI</i> <i>GDP</i>		<i>WGE</i> <i>EMPD</i>				
	<i>RDMN</i>	<i>RDI</i>		<i>RDWG</i> <i>WGE</i> <i>RDMN</i>				
	<i>WGE</i>	<i>PGDP</i> <i>GDP</i>	<i>PTGDP</i>	<i>WGE</i>				
	<i>RDWG</i>	<i>RDI</i>		<i>RDWG</i>				
Identities	<i>UR</i>			<i>EMPL</i> <i>LF</i>				
	<i>LF</i>			<i>LFPR</i>				<i>POP15</i>
	<i>EMPL</i>			<i>EMPD</i> <i>RDMN</i>				



Appendix A : Model structure – Monetary sector/Public finance

Monetary sector

Dependent Variables		Independent Variables						
		Demand/ Prices	Supply Side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance	Exogenous Variables
Behavioral Equations	M2	PGDP GDP INFR				RCB M2	CGE CGR	
	RCB	INFR				M2 RCB		

Public finance

Dependent Variables		Independent Variables						
		Demand/ Prices	Supply Side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance	Exogenous Variables
Behavioral Equations	TXR	GDP PGDP						
	CGE	GDP PGDP					CGE	
Identities	GBB						CGR CGE	
	CGR						TAXR	RGE RGO



Appendix A : Model structure – Foreign trade

Foreign trade

Dependent Variables		Independent Variables						
		Demand/ Prices	Supply Side	Wage/ Employment	Foreign Trade	Monetary Sector	Public Finance	Exogenous Variables
Behavioral Equations	<i>EXCB</i>				<i>PX</i>			<i>IMW</i> <i>YEN</i>
	<i>IMCB</i>	<i>GDP</i>			<i>PM</i> <i>ER</i> <i>IMCB</i>			
	<i>EXSNB</i>				<i>EXCB</i>			
	<i>IMSNB</i>				<i>IMCB</i> <i>IMSNB</i>			
	<i>PX</i>	<i>WPI</i>			<i>ER</i> <i>PX</i> <i>PM</i>			
	<i>PM</i>							<i>PMO</i> <i>YEN</i>
	<i>ER</i>	<i>WPI</i>			<i>EXCB</i> <i>IMCB</i> <i>EXSNB</i> <i>IMSNB</i>			<i>PWW</i> <i>YEN</i>
	<i>NCB</i>				<i>NTB</i> <i>NSNB</i> <i>NNTRB</i>			
Identities	<i>NTB</i>				<i>EXCB</i> <i>IMCB</i>			
	<i>NSNB</i>				<i>EXSNB</i> <i>IMSNB</i>			<i>EXSFB</i> <i>IMSFB</i>



Appendix B : List of variables

1. Endogenous Variables

<i>CGE</i>	Expenditures of Central Government (Billion won at current prices)
<i>CGR</i>	Revenues of Central Government (Billion won at current prices)
<i>CPI</i>	Consumer Price Index (1990=100)
<i>CRD</i>	Gross Consumption Expenditures in Non-R&D Sector (N/A, billion won at constant prices)
<i>CPVRD</i>	Private Consumption Expenditures in Non-R&D Sector (N/A, billion won at constant prices)
<i>DPI</i>	Disposable Income (N/A, billion won at constant prices)
<i>EMPD</i>	Number of the Employed in Non-R&D Sector (Thousand persons)
<i>EMPDN</i>	Number of the Employed at the Natural Rate of Unemployment (Thousand persons)
<i>EMPL</i>	Number of the Employed (Thousand persons)
<i>ER</i>	Exchange Rates (won/US dollar)
<i>EX</i>	Exports of Goods and Services (N/A, billion won at constant prices)
<i>EXC</i>	Commodity Exports (N/A, billion won at constant prices)
<i>EXCB</i>	Commodity Exports (BOP, million dollars at constant prices)
<i>EXSN</i>	Non-Factor Income from Abroad (N/A, billion won at constant prices)
<i>EXSNB</i>	Non-Factor Income from Abroad (BOP, million dollars at constant prices)
<i>GBB</i>	Government Deficits (Billion won at current prices)
<i>GDP</i>	Gross Domestic Product (N/A, billion won at constant prices)
<i>IM</i>	Imports of Goods and Services (N/A, billion won at constant prices)
<i>IMC</i>	Commodity Import (N/A, billion won at constant prices)
<i>IMCB</i>	Commodity Import (BOP, million dollars at constant prices)
<i>IMSN</i>	Non-Factor Income to Abroad (N/A, billion won at constant prices)
<i>IMSNB</i>	Non-Factor Income to Abroad (BOP, million dollars at constant prices)



Appendix B : List of variables

<i>INFR</i>	Rate of Inflation (%)
<i>KIHRD</i>	Construction Investment in Non-R&D Sector (N/A, billion won at constant prices)
<i>KIRD</i>	Gross Fixed Capital Formation in Non-R&D Sector (N/A, billion won at constant prices)
<i>KIQRD</i>	Plant/Equipment Investment in Non-R&D Sector (N/A, billion won at constant prices)
<i>KSQRD</i>	Capital Stocks in Plant and Equipment (Non-R&D) (Billion won at constant prices)
<i>KSHRD</i>	Capital Stocks in Construction (Non-R&D) (Billion won at constant prices)
<i>KSTRD</i>	Capital Stocks in Non-R&D Sector (Billion won at constant prices)
<i>LF</i>	Economically Active Population (Thousand persons)
<i>LFPR</i>	Participation Rate in Economic Activities (%)
<i>M2</i>	Money Supply (End of year, billion won)
<i>NSNB</i>	Invisible Balance (BOP, million dollars at constant prices)
<i>NTB</i>	Trade Balance (BOP, million dollars at constant prices)
<i>PGDP</i>	GDP Deflator (1990=100)
<i>PM</i>	Import Price Index (Commodities, in dollars, 1990=100)
<i>PTGDP</i>	Potential GDP (Billion won at constant prices)
<i>PX</i>	Export Price Index (Commodities, in dollars, 1990=100)
<i>RCB</i>	Yields of Corporate Bonds (Average, %)
<i>RDI</i>	R&D Investment (Billion won at constant prices)
<i>RDIPV</i>	Private R&D Investment (N/A, billion won at constant prices)
<i>RDKPB</i>	Public R&D Stocks (Billion won at constant prices)
<i>RDKPV</i>	Private R&D Stocks (Billion won at constant prices)
<i>RDMN</i>	Number of researchers (Thousand persons)
<i>RDSTK</i>	R&D Stocks (Billion won at constant prices)



Appendix B : List of variables

<i>RWG</i>	Monthly Wage of Workers in Mining and Manufacturing (thousand won at constant prices)
<i>RDWG</i>	Annual R&D Personnel Expenses per Researcher (million won at current prices)
<i>TXR</i>	Tax Revenues (Billion won at current prices)
<i>UR</i>	Rate of Unemployment (%)
<i>URSTR</i>	Natural Rate of Unemployment (%)
<i>WGE</i>	Monthly Wage of Worker in Mining and Manufacturing (Thousand won at current prices)
<i>WPI</i>	Producer's Price Index (1990=100)

2. Exogenous Variables

<i>BCP</i>	Construction Permits (10 thousands square meters)
<i>CPBRD</i>	Government Expenditures in Non-R&D Sector (N/A, billion won at constant prices)
<i>EXSFB</i>	Factor Income from Abroad (BOP, million dollars at constant prices)
<i>IMSFB</i>	Factor Income to Abroad (BOP, million dollars at constant prices)
<i>IMW</i>	Imports of OECD (Billion dollars at constant prices)
<i>KINV</i>	Inventories (N/A, billion won at constant prices)
<i>LDBC</i>	Commercial Banks' Investment Fund for Plants and Equipments (End of year, billion won)
<i>MORI</i>	Manufacturing Operation Ratio Index (1990=100)
<i>MORIB</i>	Average Manufacturing Operation Ratio Index (1990=100)
<i>NNTRB</i>	Transfer Balance (BOP, million dollars at constant prices)
<i>PMO</i>	Prices of Crude Petroleum (in dollars, 1990=100)
<i>POP15</i>	Population above 15 (Thousand persons)
<i>PWW</i>	GDP Deflator of OECD (1990=100)



Appendix B : List of variables

<i>RDIPB</i>	Public R&D Investment (N/A, billion won at constant prices)
<i>RGE</i>	Net Revenue of Government Owned Corporate (Billion won at current prices)
<i>RGO</i>	Other Government Revenues (Billion won at current prices)
<i>SDI</i>	Statistical Discrepancies (N/A, billion won at constant prices)
<i>YDAY</i>	Annual Workdays in Mining and Manufacturing (12monthly workdays, days)
<i>YDAYB</i>	Average Annual Workdays in Mining and Manufacturing (days)
<i>YEN</i>	Yen per US Dollar (Yen/Dollar)
<i>Dij</i>	Dummy, $ij=1$, for year ij ; otherwise=0
<i>DDijst</i>	Dummy, $ij-st=1$ for year $ij-st$; otherwise=0