The Effect of R&D Investments
on Economic Inequality in Korea[*]

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In this paper we examine the effects of R&D investments on economic inequality in Korea using a dynamic Computable General Equilibrium model. In the model, we classify the household sector into 10 income groups and the production sector into 28 industries. The policy simulation is designed to investigate the effect of R&D investments in 28 industries on income distribution during 2008-2030 period based on the assumption that the R&D investments follow the recent trend.

The policy simulation uncovered the following findings: Firstly, R&D investments aggravate income distribution while they significantly improve most major economic variables such as GDP, investments, and consumption in a period from 2008-2030. Thus, there exists a trade-off between efficiency and equity aspects of R&D. We try to explain the reason why R&D investments aggravate income distribution and find it results from the relative distribution of capital income distribution to labor income distribution. Secondly, we examine the welfare effect of R&D investments based on the equivalent variation. As expected, R&D investments increased the welfare of upper-income households relative to lower-income ones. We find that those in the upper-income class bracket consume more R&D intensive goods than those classified as lower income, and furthermore, the prices of R&D intensive goods will probably decrease more due to R&D investments.

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1. INTRODUCTION

In the 21st Century, socioeconomic environments are changing rapidly as well as the paradigm of the world economy as globalization and aging societies have become the crucial agenda of most countries, Korea among them. Knowledge capital and human capital will play an especially important role compared to physical capital. The Republic of Korea (hereafter Korea) will be caught in the trap of having a low potential for economic growth without a new economic growth strategy, affecting the economy's total productivity as a whole.

It is necessary for Korea to develop innovation in science and technology and accumulate the knowledge capital and the human capital. In order to achieve this goal, we must increase not only investments in R&D but its efficiency. Increasing investments in R&D is expected to raise GDP through various channels in the economy. They will augment the knowledge capital stock which then increases total factor productivity, which then leads to a higher GDP. The R&D investments may have labor saving technical progress and/or capital saving technical progress. Either way, more funding of R&D will induce cost savings in the production process, eventually having a positive effect on GDP.

The R&D investments, however, may have a negative effect on income distribution and economic welfare. Most, if not all, R&D investments are within high-tech industries such as information technology, biology, communication, and environment industries. Those industries are shown to be very R&D intensive since technological innovations require a high level of scientific and technical labor and equipment, implying a high level of R&D investments as a whole. One of the crucial economic achievements of R&D investments is the lower price of consumer goods, which eventually betters a household's welfare. The upper-income households then may enjoy low-cost intensive goods compared to lower-income households. As a result, R&D investments may aggravate welfare distribution.

The purpose of the study is to analyze the economic effects of R&D

investment from 28 industries in Korea in a more scientific and systematic way.   We use the dynamic Computable General Equilibrium (hereafter CGE) Model to analyze the economic effects of industrial R&D investments for 28 industries in terms of both efficiency and equity.   The policy simulation analysis of R&D investments may be classified into two types: partial equilibrium analysis and general equilibrium analysis.   Recently, the general equilibrium approach has been used more often than before due to the very rapid development of computation devices and software.   To examine the effect of expansive policy changes as well as consider many more industry sectors and consumers, Shoven and Whalley (1972) suggest a Computable General Equilibrium Model, which is very powerful in examining both efficiency and equity effects of various policy proposals.   In this paper we use the dynamic Computable General Equilibrium (CGE) model to examine the effects of R&D investments on the macroeconomic variables as well as income distribution of the Korean economy.

The contents of this study are as follows: In section 2, we survey the literature on R&D investments and the Computable General Equilibrium Model, coming up with a dynamic CGE model for Korea based on the variety of data.   Section 3 is our explanation of the potential effects of R&D investments on the economy.   In section 4, we examine the effects of R&D investments of 28 industries assuming that the recent trends of R&D investments for each industry will continue throughout the period from 2008-2030.   We examine the effect of R&D investments on income distribution and the distribution of economic welfare as well as macroeconomic variables. Our study concludes in section 5, using the results to suggest any policy implications.

2. DYNAMIC CGE MODEL

2.1. Literature Survey

There are many works on the dynamic CGE Model, such as Fullerton *et al*. (1983), Ballard *et al*. (1985), Auerbach and Kotlikoff (1987), Fullerton and Rogers (1993), to name a few.

On the other hand, there are also many works on the relationship between R&D and income distribution like Garcia-Penalosa and Turnovsky (2006), Chou and Talmain (1996), Li (1998), Zweimuller (2000), and Foellmi and Zweimuller (2006). However, these especially handle the effects of wealth inequality on growth. Also, Bertola *et al*., (chapter 10, 2006) studies income distribution between entrepreneurs and workers.

We will discuss the following works: Berman-Bound-Griliches (1994), Aghion (2002), Grossmann (2007), Chu (2010), Latzer (2011).

Berman-Bound-Griliches (1994) found that R&D expenditure and computer purchases could explain as much as 70% of the move away from production to non-production labor in the period 1979-1987.

Aghion (2002) tried to explain why within-group wage inequality has been increasing sharply in developed countries like the U.S. and UK for the past thirty years, and found that it resulted partly from an innovation response to the increased supply of skilled labor. He used Schumpeterian Growth theory which offers a suitable framework for a more general analysis of the relationship growth and income inequality. His study implies that between-versus within-group wage inequality implies labor market policy during the transition to a new technological paradigm.

Grossmann (2007) compared the positive and normative implications of two alternative measures to promote R&D-based growth with an overlapping generation model. The R&D subsidies to firms may be harmful to both productivity growth and welfare, and furthermore, earnings inequality (p. 13). However, public-funded education devoted to teaching scientific and engineering skills unambiguously promotes growth and is neutral for earning

distributions. Importantly, this holds true although intertemporal knowledge spillovers are the only externality from a firm's R&D spending in the model. The main reason is a congestion effect under a public education system, implying that public education is a good rival and R&D activity requires employees' resources with specialized skills. Income inequality is divided into two classifications: income inequality within R&D workers and between R&D labor and production workers. Income inequality within the group of R&D workers is calculated from the top to bottom earners within this group, but inter-group inequality is measured from the ratio of average income between two groups, i.e., R&D labor and production workers. As a result, this study shows that a more desirable mean to promote R&D is to increase public spending devoted to educating scientists and engineers.

Chu (2010) developed a quality-ladder growth model with wealth heterogeneity and an elastic labor supply and claimed that strengthening patent protection increases both economic growth and income inequality. The increase in income inequality results from raising the return on assets. However, whether it increases consumption inequality depends on the elasticity of intertemporal substitution. He showed that strengthening patent protection worsens income inequality by more than consumption inequality when using the U.S. data. If the elasticity of intertemporal substitution is less (greater) than unity, strengthening patent protection would increase (decrease) consumption inequality. He found that the patent policy may partly explain the recent trend of income and consumption inequality in the U.S. The logic is as follows: Strengthening patent protection increases R&D and thus drives up the rate of return on assets. The income of asset-rich households more than the asset-poor households then increases. The higher growth rate also increases the fraction of assets that needs to be saved. Therefore, whether the relative increase between the asset-wealthy households and asset-poor households increases or decreases depends on the elasticity of intertemporal substitution.

Latzer (2011) showed that inequality has an impact on the allocation of the overall R&D effort between incumbents and challengers with a

Schumpeterian model of growth and inequality. He also claimed that a higher level of inequality leads to a bigger share of the overall R&D investment to be carried out by quality leaders.

There are few studies on the economic effect of R&D investments for Korea. Just recently Chun *et al.* (2012) analyzed the optimal portfolio of knowledge and human capital investment for Korea.

2.2. Model Overview

Figure 1 shows a brief structure of the model developed in this paper. Employing labor and capital, a firm produces final goods (Y_i) and sells it domestically and abroad. In this process, government levies an indirect tax or a subsidy on the final goods. After paying tariffs and/or commodity taxes, imported goods flows into Armington market where they are treated as imperfect substitute for domestic counterparts, something shown in the figure. The compounded consumption goods at Armington market is distributed to households, investment, and the public sector,[1] and is

Figure 1   Structure of Model

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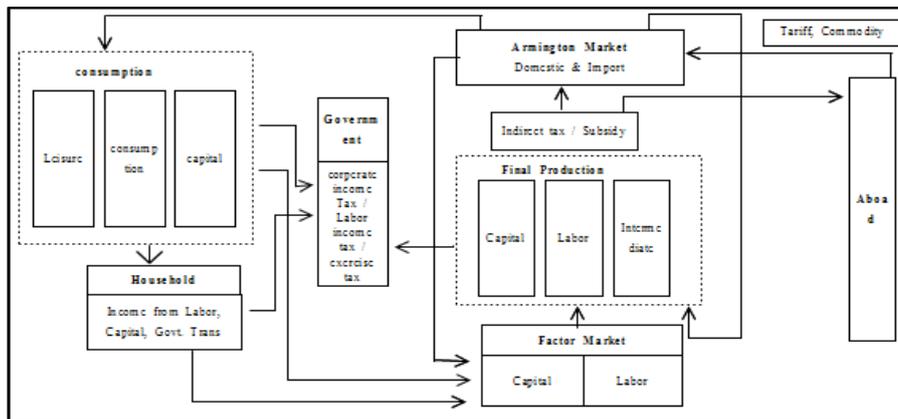
[1] Government sector does not appear in figure 1 for simplification. Government levies various taxes and expenditure tax revenue for providing public goods and for transferring to household.

used for intermediate goods in the industry. Within Household there are ten different income groups. They maximize their intertemporal utility given their budget constraints. Household earns labor income and capital rental income and pays income taxes.

2.2.1. Time scope

Tax and public finance policy induces a static as well as dynamic impact on all agents in the economy. In order to consider both effects in this paper, we construct a dynamic computable general equilibrium model covering 23 periods within the time interval from 2008 to 2030. We assume that all agents

Table 1 Scope of Industry, Consumption, and Income Group

Industry		Consumption	Income Group
S01 Agricultural and marine poducts	S15 Transport equipment	C01 Food products and beverages	W01. 0-10%
S02 Mineral products	S16 Furniture and manufacturing products	C02 Housing expense	W02. 10-20%
S03 Food products and beverages	S17 Electric power, gas and water service	C03 Light, heat and water services	W03. 20-30%
S04 Textile and leather products	S18 Construction	C04 Furniture and appliances	W04. 30-40%
S05 Wood and paper products	S19 Wholesale and retail trade	C05 Clothing and footwear	W05. 40-50%
S06 Printing, publishing and reproduction	S20 Restaurant and accommodation	C06 Health and medical services	W06. 50-60%
S07 Petroleum and coal products	S21 Transport and storage	C07 Education	W07. 60-70%
S08 Chemical products	S22 Telecommunications and broadcasting	C08 Cultural recreation	W08. 70-80%
S09 Non-metallic mineral products	S23 Financial and insurance	C09 Traffic and communication	W09. 80-90%
S10 Basic metal products	S24 Real estate and Business activities	C10 Others	W10. 90-100%
S11 Metal products	S25 Public administration and national defense		
S12 General machinery	S26 Education and health		
S13 Electrical and electronic instruments	S27 Social and other services		
S14 Precision instruments	S28 Others		

have ability of perfect foresight in that they perfectly know all of the impact
that policy change will have on future.

2.2.2. Scope of industry, household, and consumption goods

Table 1 shows the scope of industry, consumption goods, and income
group for analysis.   Industry is divided by 28 industries.   Based on
Household Survey, we consider 10 income groups who are representative of
how a household spends its income on 10 different consumption goods.
Therefore, the model is designed to analyze both equity and efficiency issues
caused by policy change.

2.3. Model Structure

2.3.1. Household

Household consists of 10 income groups, assuming that each income
group has a representative agent who lives infinitively and is able to foresee
perfectly.   Each consumer maximizes his intertemporal utility function
(U_w) subject to an intertemporal budget constraint.   It is also assumed that
intertemporal utility function is CES (constant elasticity of substitution)
between full consumption $(Z_{w,t})$ at any points in time t

$$\max_{\alpha \quad L} \quad U_w(Z_{w,t}) = \sum_{t=0}^{\infty} \beta^t \frac{Z_{w,t}^{1-\theta}}{1-\theta}, \tag{1}$$

$$\text{s.t.} \quad Z_{w,t} = [\alpha \, Q_{w,t}^{\rho} + (1-\alpha)(H_{w,t} - L_{w,t})^{\rho}]^{\frac{1}{\rho}}, \tag{2}$$

where index indicates income level, β is time discount rate, $1/\beta$ is
intertemporal elasticity of substitution. $L_{w,t}$ is working time by income
group at time t.   Thus, the amount of leisure for w income group is total
time endowment $(H_{w,t})$ minus working time such as $H_{w,t} - L_{w,t}$.   The full
consumption of goods is a CES function of consumption composite goods
$(Q_{w,t})$ and leisure. $1/(1-\rho)$ indicates the elasticity of substitution

between consumption composite goods and leisure, and α in equation (2) shows a share of consumption. Share parameter α and elasticity of substitution parameter ρ should be different in every equation below. But we express s same symbol for convenience.

Intertemporal budget constraint of w income group is as follows.

$$
\begin{aligned}
& \sum_t P_{Q,t} Q_{w,t} + \sum_t P_{i,t} I_{w,t} + \sum_t R_t K^d_{w,t} \\
& = \sum_t W_{w,t} L_{w,t} + \sum_t R_t K^s_{w,t} + \sum_t Tr_{w,t}.
\end{aligned}
\tag{3}
$$

All prices shown in equation (3) are after tax prices reflecting time discount. Thus, $P_{Q,t}$ is after tax price discounted by interest rate r. In steady state, $P_{Q,t}$ is equal to $\dfrac{1}{(1+r^*)^{t-1}} P_{Q,0}$ where $P_{Q,0}$ is price of base year. $P_{i,t}$ is price of investment goods, $W_{w,t}$ is after tax wage, R_t is after tax rate of return to capital. $I_{w,t}$ is investment of w income group. $K^d_{w,t}$ and $K^s_{w,t}$ represent supply of and demand for capital, respectively. $Tr_{w,t}$ is government transfer to w income group.

In equilibrium, total supply of labor ($\sum_w L_{w,t}$) should be equal to total demand for labor ($\sum_i L_{i,t}$), and also total supply ($\sum_w K^s_{w,t}$) of capital should be equal to total demand for capital ($\sum_i K_{i,t} + \sum_w K^d_{w,t}$).

As in figure 2, nested consumption goods $Q_{w,t}$ is a CES function of household capital and consumption goods, $C_{w,c,t}$.

$$
Q_{w,t} = [\alpha_1 K^d_{w,t} + (1-\alpha_1) C^\rho_{w,c,t}]^{\frac{1}{\rho}}.
\tag{4}
$$

$C_{w,c,t}$ indicates one of the consumption goods listed in table 1, a CES aggregates of Armington goods.

$$
C_{w,c,t} = [\sum_i^{28} \alpha_i (XA_{w,c,i,t})^\rho]^{\frac{1}{\rho}},
\tag{5}
$$

Figure 2   Structure of Consumption
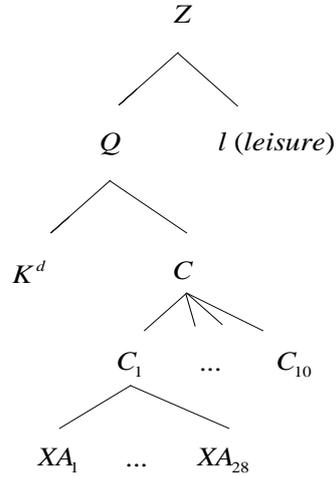
where $XA_{w, c, i, t}$ is i Armington goods for producing c consumption goods for w income group at time t.

2.3.2. Production structure

The structure of production is shown in figure 3.   We employ constant-elasticity-of-substitution (CES) functional forms for the production technology.   Specifically:

$$Y_{i, t} = \bar{A}_{i, t} \left[\alpha KL_{i, t}^{\rho} + (1-\alpha) XA_{i, t}^{\rho} \right]^{\frac{1}{\rho}}, \qquad (6)$$

where $Y_{i, t}$ is final production good, $KL_{i, t}$ is physical-knowledge capital ($K_{i, t}$) and labor ($L_{i, t}$) composite goods, and $XA_{i, t}$ is Armington goods. $\bar{A}_{i, t}$ is a scale coefficient representing the technical externality which will be explained shortly below in detail.

In top part of figure 3, $Y_{i, t}$ is converted into export goods ($XE_{i, t}$) and domestic goods ($XD_{i, t}$) as shown in equation (7).

Figure 3   Production Structure
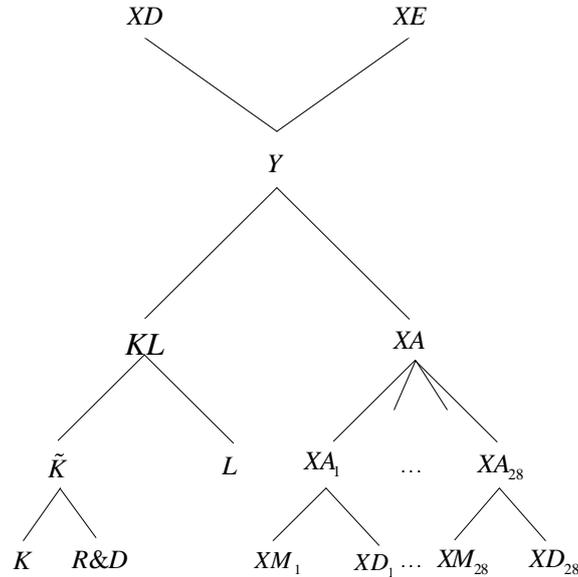
$$\left[\alpha XE_{i,t}^{\rho} + (1-\alpha)XD_{i,t}^{\rho}\right]^{\frac{1}{\rho}} = Y_{i,t}, \tag{7}$$

In equation (6), $KL_{i,t}$ is physical-knowledge capital ($K_{i,t}$) and labor ($L_{i,t}$) composite goods as follows.

$$KL_{i,t} = [\alpha K_{i,t}^{\rho} + (1-\alpha)L_{i,t}^{\rho}]^{\frac{1}{\rho}}. \tag{8}$$

In equation (8) physical-knowledge capital ($K_{i,t}$) is a composite goods of physical capital ($K_{i,t}$) and knowledge capital ($A_{i,t}$) as follows.

$$K_{i,t} = A_{i,t} + K_{i,t}. \tag{9}$$

Following Goulder and Schneider (1999), we assume that knowledge

capital has a feature of exclusiveness and is accumulated as follows.

$$A_{i,t+1} = (1-\delta_a)A_{i,t} + RD_{i,t},\qquad(10)$$

where $A_{i,t}$ is knowledge capital and $RD_{i,t}$ is R&D investment in sector i at time t, and δ_a denotes the depreciation rate of knowledge capital. R&D investments augment the stock of knowledge.

In this paper we classify technical progress into two categories — exclusive technical progress and non-exclusive technical progress. The latter causes the positive external effect so that every firm can enjoy spillover benefits from R&D undertaken by other firms. These knowledge spillover enters through scale coefficient $\overline{A}_{i,t}$. We may notice that except for $\overline{A}_{i,t}$, constant returns to scale holds. However, the presence of $\overline{A}_{i,t}$ makes production function increasing returns to scale function.

The value of $\overline{A}_{i,t}$ which represents the total factor productivity of industry i at time t is determined in the model based on equation (11).

$$\overline{A}_{i,t} = (Y_{i,t})^{\frac{1}{1-\beta}} - Y_{i,t}.\qquad(11)$$

In equation (11), β denotes the coefficient of technology diffusion. Clearly β is less than 1. $\overline{A}_{i,t}$ increases proportionately, with other things being equal, as β increases. Also $\overline{A}_{i,t}$ increases in proportion to output of industry i at time t.

Back in equation (6), Armington goods are CES function of domestic goods ($XD_{s,t}$) and imported goods ($XM_{s,t}$) as shown in equation (12). We use index s instead of i to distinguish Armington goods used in industry and from ones used in other sectors.

$$XA_{s,t} = [\alpha XD_{s,t}^{\rho} + (1-\alpha)XM_{s,t}^{\rho}]^{\frac{1}{\rho}},\qquad(12)$$

where $XA_{s,t}$ stands for production goods in industry s at time t.

Armington goods produced in industry *i* are distributed to other industries as intermediary goods and to households, government as well as investment sector as final consumption goods.

$$XA_{s,t} = \sum_i XA_{s,i,t} + \sum_w \sum_c XA_{w,c,s,t} + XA_{inv,s,t} + XA_{g,s,t}, \qquad (13)$$

where $XA_{s,i,t}$ is *s* Armington goods used in industry *i* as intermediary goods, $XA_{w,c,s,t}$ is *s* Armington goods consumed by income group *w*, $XA_{inv,s,t}$ is one used by investment sector, and $XA_{g,s,t}$ is one used in government sector at time *t* respectively.

2.3.3. Factor market

i) Labor market

Aggregate labor input consists of labor supplied by each income group. Individual labor input differs only in terms of amount of tax burden because of the progressive structure of labor tax in Korea. Compounded each individual labor input at the labor market, aggregated labor is distributed into each industry. Equation (14) shows the process of compounding an individual labor input. Equation (15) shows distribution of a compounded labor into *i* industry. As shown in equation (14), labor input is CES aggregation of individual labor.

$$L_t = \left(\sum_w \alpha_w L_{w,t}^\rho \right)^{\frac{1}{\rho}}, \qquad (14)$$

$$L_t = \sum_i L_{i,t}. \qquad (15)$$

ii) Capital market

As in the labor market, capital market aggregates individual capital with imperfect substitution as in equation (16) and distributes it into each industry and household.

$$K_t = \left(\sum_w \alpha_w K_{w,t} \right)^{\frac{1}{\rho}}, \tag{16}$$

$$K_t = \sum_i K_{i,t} + \sum_w K_{w,t}^d, \tag{17}$$

where K_t is total capital stock, $K_{w,t}$ is individual capital stock supplied by w income group. $K_{i,t}$ is capital stock used in i industry, and $K_{w,t}^d$ is capital stock demanded by w income group.

Unlike in Fullerton and Rogers (1993) and Yi *et al.* (2002), our model is a fully dynamic model which is solved all period simultaneously. Each period is connected by accumulation of capital stock. The capital stock of the $t+1$ period is accumulated by following law of motion:

$$K_{t+1} = (1-\delta)K_{i,t} + I_t, \tag{18}$$

where δ is depreciation rate and I_t is investment at period t.

2.3.4. Government

Government collects tax and spends it on consuming and transferring to household as equation (19) shows.

$$\Phi_t + P_{ex,t} D_t = \sum_i \tau_{1,i} r_t K_{i,t} + \sum_i \tau_{2,i} w_t L_{i,t}$$
$$+ \sum_i (\tau_{3,i} + \tau_{4,i}) P_{em,i,t} XM_{i,t} + \sum_i (\tau_{5,i} + \tau_{6,i}) P_{\mu,i,t} Y_{i,t}, \tag{19}$$

where Φ_t is total government tax revenue, and $D_{g,t}$ is government deficit that is defined as its total revenue minus total expenditure. $P_{ex,t}$ is the exchange rate, which we use as cost of government deficit in order to allow government to finance its deficit from abroad. $\tau_{1,i}$ is an effective tax rate on corporate income, $\tau_{2,i}$ is an average tax rate on labor income, $\tau_{3,i}$ is tariff rate, and $\tau_{4,i}$ is imported commodity tax rate. $\tau_{5,i}$ is the indirect

tax rate and $\tau_{6,i}$ is subsidy rate. $P_{u,i,t}$ is the price of i goods before tax. r_t and w_t are wage and rate of returns to capital before tax. $P_{xm,i,t}$ is before tax price of imported goods.

On the other hand, government expenditure (Γ_t) is defined as follows:

$$\Gamma_t = \sum_s P_{XA_s,t} XA_{s,t} + \sum_w Tr_{w,t}, \qquad (20)$$

where $P_{XA_s,t}$ is before tax price of s Amington goods $(XA_{s,t})$ and $Tr_{w,t}$ is government transfer to w income group.

We can consider two kinds of budget constraints: one is balancing the government budget period by period. The other one is balancing the government budget over an infinite period as shown in equation (21). We assume the intertemporal government budget constraint in this paper.

$$\sum_{t=0} \Phi_t + \sum_{t=0} P_{ex,t} D_t = \sum_{t=0} \Gamma_t. \qquad (21)$$

We calibrate the government budget to balance without levying endogenous tax in base year. After new policy is introduced, however, the government budget preserves the balance through adjusting consumption tax rate endogenously. Consumption tax rate is endogenously determined in balancing over whole period.

2.4. Input Data

In this paper, the base year is 2008 with the input data for this model come from various sources; 2008 Input-Output Tables, Household Survey, the Statistical Yearbook of National Tax, Financial Statement Analysis, the Korea Statistical Yearbook, and previous studies. Since Household Survey and Financial Statement Analysis 2008 are based on surveys, we need to consistently connect to aggregate macro data. In order to do that, we calculate the ratio of consumption, investment, income, etc., first. Applying

Table 2　Social Account Matrix

	Domestic Goods	Import Goods	Consumption	Final Demand			Value Added	Tax	Export	Import	Total
				Household	Government	Investment					
Domestic Goods	(1) 28×28		(7) 28×10×10		(12) 28×1	(15) 28×1			(20) 28×1		
Import Goods	(2) 28×28		(8) 28×10×10		(13) 28×1	(16) 28×1					
Consumption				(9) 10×10							
Final Demand — Household					(14) 10×1		(18) 10×2				
Final Demand — Government						(17) 1×1		(19) 1×6			
Final Demand — Investment				(10) 1×10						(21) 1×1	
Value Added	(3) 2×28			(11) 2×10							
Tax	(4) 4×28	(5) 2×28									
Export									(22) 1×1		
Import		(6) 1×28									
Total											

these ratios to macro data, we construct micro and macro-consistent data sets which are components of SAM (Social Account Matrix) in table 2.

Table 2 shows the economic transactions of Korea in 2008.　A SAM is a comprehensive, economy-wide data framework, typically representing all of the transaction of the economy.

More technically, a SAM is a square matrix in which each account is represented by a row and a column.　Each cell shows the payment from the account of its column to the account of its row — the incomes of an account appear along its row, its expenditures along its column.　The dimension in table 2 represents the sub-transaction of each account.

2.5. Calibration and Solution Method

Calibration is the process where numerical values are assigned to the parameters of the model.　This is typically done by constructing a SAM which matches the markets and constraints of the agent in the theoretical model.　In order to deal with this problem, that data for investment and

capital stock has to be fitted into a theoretical model, we calibrate the subject to the assumption that the base year is a steady state.   In a steady state, the relationship of investment and capital stock is defined as

$$K^* = \frac{\text{capital income}}{\text{interest rate} + \text{depreciation rate}},$$

$$I^* = (\text{growth rate} + \text{depreciation rate}) \times K^*,$$

In this paper, we assign the interest rate as 0.06, depreciation rate as 0.07, and growth rate as 0.05.   Using this value, we calculate investment in steady state and manipulate investment and consumption in SAM to maintain consistency of the final demand and supply.   Since interest rate in steady state equals to $((1/\beta)-1)$, β is 0.943.

In the general case of the Ramsey Model, we solve the dynamic model assuming balance growth.   In a balance growth model, all variables are growing at the same rate such that $Y^* = Y_0(1+g)^{t-1}$ where Y_0 is the value of base year and g is the growth rate.   Further, all prices are discounted by interest rate such that

$$P_t = \frac{1}{(1+r)^{t-1}}.$$

By using the formula, we assign the dynamic paths of all variables and prices.[2]

The numerical model can only be solved for a finite number of periods, hence some adjustments are required to produce a model which, when solved over a finite horizon, approximates the infinite horizon choices.   According to Rutherford (1994), we add a constraint on the growth rate of investment and GDP in the terminal period such that they are the same.

We choose the other parameters based on the following previous research:

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[2] See Rutherford (1994) for more detail to calibrate for dynamic model.

Fullerton and Rogers (1993), Sonn and Shin (1997), Cho (2000), Yi *et al*. (2002), Bernstein *et al*. (1999), Goulder and Schneider (1999).

We assume that all sectors have the same value of elasticity of substitution. According to Sonn and Shin (1997) who used 2-4, we choose 3.0 of constant elasticity of transformation between exports and domestic goods.   The elasticity of substitution between labor and capital is one in which this functions has Cobb-Douglas production technology. Using Fullerton and Rogers (1993) and Yi *et al*. (2002), we assume that the elasticity of capital-labor compound good and Armington goods is 0.   We assign 3.0 to the elasticity of Armington transformation with same reason for choosing an elasticity of transformation between exports and domestic goods.

The elasticity of intertemporal substitution $(1/\theta)$ is 0.5 based on Goulder and Schneider (1999) and Bernstein *et al*. (1999).   We choose 0.8 for elasticity of compound consumption good and leisure according to Rasmussen and Rutherford (2001).

The model in this paper is programmed in GAMS language.   Under the GAMS platform, the dynamic structure of the model is written in MPSGE, which is an abstract, high-level language for formulating CGE model.   The equilibrium prices and quantities of the model are solved by using the PATH solver, a generic algorithm for solving MCP (Mixed Complementary Programming) problems.   The main advantage of programming in MPSGE is that the solution algorithm and the economic model can be separated. This separation makes it possible for users to make changes in model structure, and to introduce new assumptions, without extensive re-programming and debugging.

3. THE CHANNELS OF THE EFFECTS OF R&D INVESTMENTS ON ECONOMY

Investments in R&D affect the economy in various ways.   We can classify the effects of R&D into two categories: efficiency aspects and equity

aspects.   R&D investments will increase the size of the pie, GDP on the one hand.   Also, R&D investments will affect the distribution of the pie, the income distribution and welfare changes of ten income class households.

3.1. The Effect of R&D Investments on GDP

There are two channels for industrial R&D investments to affect industrial outputs and GDP: First, knowledge capital has a feature of exclusiveness and is accumulated, as shown in equation (10).   We postulate Hicks-neutral or capital augmenting technical progress such that R&D investments augment the capital inputs as in equation (9).   R&D investments may substitute physical capital to some extent.   In some sense R&D investment in industry *i* will increase output of own industry without affecting other industries.

Figure 4   Channels of the Effect of R&D Investments on the Economy
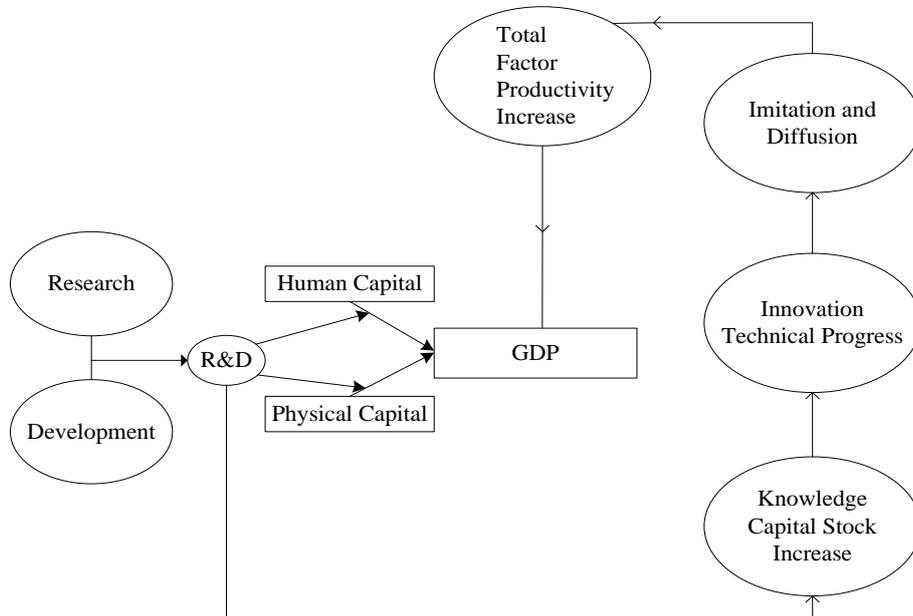
Second, knowledge capital has positive external effect such that all firms enjoy spillover benefits from R&D under taken by other firms.   In other words R&D investments enhance the total factor productivity through knowledge accumulation.

In both channels, R&D investments will increase industrial outputs and GDP of the economy.   R&D investments will increase investments, consumption, and capital stock as well as labor supply.   Theoretically and empirically, the effects of R&D investments on the major macroeconomic variables are significantly positive.

3.2. The Effect of R&D Investments on Income Distribution

The effects of R&D on the economy in terms of equality, however, do not seem so favorable.   There are various ways of R&D investments affecting the income distribution and welfare changes of households in ten income classes.   First, we will examine the effect of R&D investments on income distribution theoretically.   We may compare the Gini coefficient of counter-factual equilibrium after R&D investments with that of benchmark equilibrium without any R&D investments.   The change in the Gini coefficient comes from changes in the distribution of income for households in ten income classes.   The total income (Y_i) of household i may be decomposed into labor income (wL_i) and capital income (rK_i) as shown in equation (22).

$$Y_i = wL_i + rK_i, \tag{22}$$

where Y_i = total income of income class i, L_i = labor supply of income class i, K_i = capital supply of income class i, w = wage, r = interest rate.

The Gini coefficient (G) is measured as follows.

$$G = \frac{\Delta}{2\mu}, \tag{23}$$

$$\Delta = \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} \left| y_i - y_j \right|, \tag{24}$$

where G = Gini coefficient, Δ = average income gap of whole population, n = population size.

A change in G comes from changes in Y_i which again are influenced by labor income (wL_i) and capital income (rK_i). Thus, changes in labor income distribution and capital income distribution affect the distribution of total income and Gini coefficient. R&D investments will enhance the productivities of capital and labor so that real wage and the interest rate. The distribution of capital income across income classes is more uneven than that of labor income. As a result, we expect that an increase in the rate of return to capital due to R&D may make the distribution of capital income worse than it was initially, while an increase in real wages may make the distribution of labor income better. The net effect of R&D investments on income distribution depends on the relative size of conflicting forces.

3.3. The Effect of R&D Investments on Welfare Distribution

In this section, we will examine the effects of R&D on welfare distribution in terms of equivalent variation. We use equivalent variation as welfare comparison between benchmark equilibrium and counter-factual equilibrium due to R&D investments.

Equivalent variation (EV) is a measure of how much money a consumer would pay before a price increase to avert the price increase. The value of the equivalent variation is given in terms of the expenditure function $e(\cdot, \cdot)$ as

$$EV = e(p_0, u_1) - e(p_0, u_0), \tag{25}$$

where p_0 and p_1 are the old and new prices respectively, u_0 and u_1 are the old and new utility levels respectively.

Similarly, in terms of the indirect utility function or the value function

$(v(\cdot,\cdot))$,

$$v(p_0, w) + EV = u_1, \tag{26}$$

where w is the wealth level.

The channels of R&D investments affecting welfare distribution are as follows: As explained in the previous section, production goods of 28 industries are transformed into 10 consumption goods via transformation matrix (Z-matrix). In this process, R&D investments in 28 production goods are also transformed into 10 consumption goods.

We conjecture that R&D intensities of consumption goods are determined by Z-matrix and R&D intensity of production goods.

In our model, there are 28 production goods which are transformed into 10 consumption goods.

$$\left[CI\right]_{1\times10} = \left[RD/Y\right]_{1\times28} \times \left[Z-matrix\right]_{28\times10}, \tag{27}$$

where *CI* denotes 10 consumption good's R&D intensity index, RD/Y denotes the R&D intensity that is defined to be the ratio of R&D investment to output and Z-matrix denotes transition matrix that convert production goods to consumption goods.

We suggest two important hypotheses by which the welfare effect of R&D investments is affected. First, the upper-income households consume more R&D intensive goods than the lower-income households. High-tech products such as smart phones, smart TV, and luxury cars are very R&D intensive than low-tech products, implying that upper-income households can enjoy the fruitful success of R&D investments by consuming more high-tech products than lower-income households.

Second, R&D investments will make the price of more R&D intensive products drop more than less R&D intensive products. If these two hypotheses hold, an increase in R&D investments increases the welfare of the upper-income households more than the lower income class households,

Figure 5   The Channel of the Effect of R&D Investments on Household Welfare
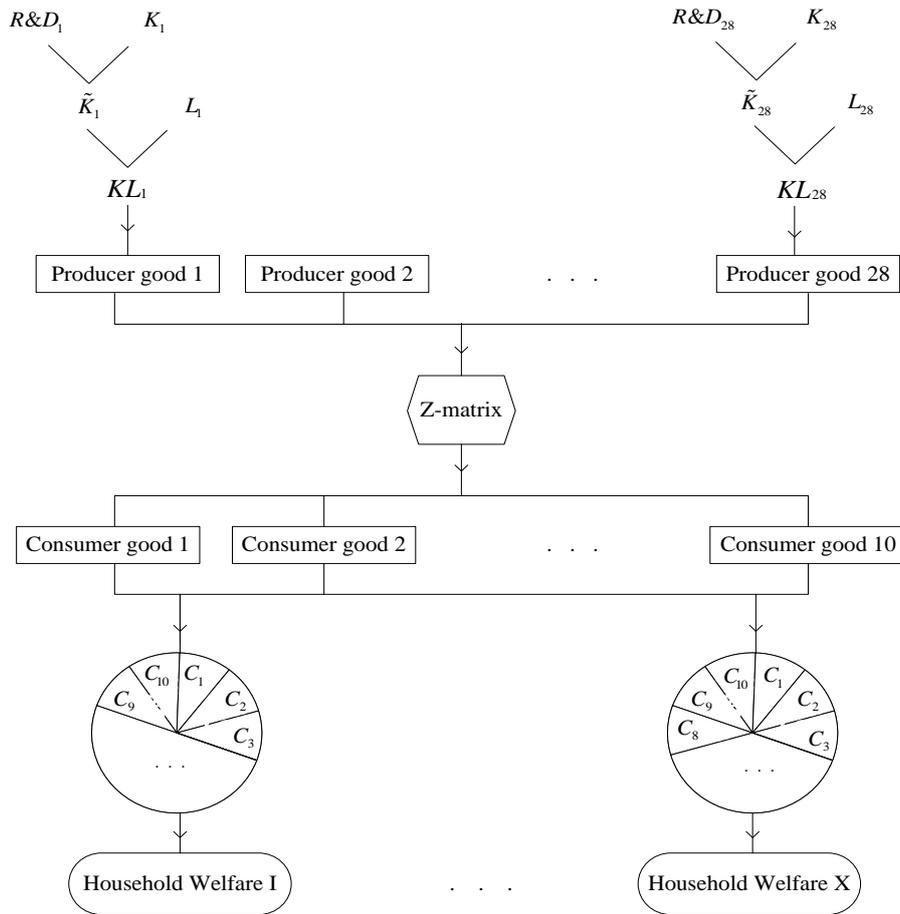
Note: 1) High-income class X consumes more R&D intensive goods.

since the upper-income households enjoy the benefits from lower price of R&D intensive products.

4. THE EFFECT OF R&D INVESTMENTS: POLICY SIMULATION

4.1. Policy Simulation Design

In the policy simulation, we try to analyze the economic effects of R&D investments, which we assume will follow recent trends, into the future. Based on the assumptions, we estimate the R&D investments for 28 industries during the period of 2008-2030 using the ARIMA (Autoregressive Integrated Moving Average) time series model. In the next stage, we analyze the economic effects of the R&D investments on terms of efficiency and equity aspects. In terms of efficiency aspects, we focus on the effects of R&D investments on the demand side of the economy such as GDP, consumption, investments, government expenditures and net export (which is export minus import). We analyze the effects on the supply side of the economy such as capital formation, labor supply, and real wage.

4.2. The Effect of R&D Investment on Major Macro Variables

The following are the main results of the policy simulation. We compare the counter-factual equilibrium with the benchmark equilibrium. The counter-factual equilibrium is one in which the R&D investments will increase following the recent trends for 28 industries. We find that in the counter-factual equilibrium the GDP will increase by 0.60% annually in comparison with the benchmark equilibrium. The consumption will increase by 0.19% annually and the investment will increase by 1.27% annually. Additionally, the government expenditures will increase 0.44% annually and the trade balance will increase by 9.62% annually.

In terms of the effects on the supply side of the economy, the capital stock will increase by 0.96% annually and the labor supply will increase by 0.32% annually. Therefore, the efficiency gain of the R&D investments will be substantial.

In this study, we estimate the elasticity of GDP with respect to the R&D investment, which is the ratio of the % increase of GDP to the % increase. The estimate of the elasticity of GDP with respect to the R&D investment for 2009 is 0.404 and will increase smoothly to reach 1.037 in 2026.   We may confirm that there exists "Increasing Returns to Scale" in R&D investments. Also, we may notice that there exists the lagged effect and the cumulative effects of the R&D investments.   The lagged effect of R&D means that the effect of R&D in the current year will be realized after a few years.   The cumulative effect of R&D refers to the fact that the effects of R&D will continue for quite a long time.

4.3. Income Distribution Effect of R&D

It is desirable to analyze the economic effects of R&D investment in terms of both efficiency and equity aspects.   On the one hand, an efficiency analysis on the effect of R&D investment focuses on the size of total pie, for instance, either GDP or social welfare.   On the other hand, an equity analysis focuses on the effect of R&D investment on the distribution of total pie among economic agents.

In section 4.2., it was shown that the effects of R&D investment on the major macro economic variables are seemingly marvelous.   Here we will analyze the equity aspect of R&D investment in terms of the welfare effect and the income distribution effect.   Since the two have slightly different implications, analyzing both will be more meaningful and fruitful.   The welfare effect of R&D investment is more sensible for analyzing the equity aspect of R&D.   However, the welfare comparison of any two states is more or less difficult because factors affecting the welfare of different income class households are often too complex, including simultaneous price scheme and income changes.   On the other hand, the income distribution effect of R&D investments can be easily analyzed based on change in the Gini coefficient.   Also, the income variable is a very good proxy variable for welfare.

Table 3   Gini Coefficients in BAU and SCN

Year	BAU	SCN	Year	BAU	SCN
2008	0.378065	0.378074	2020	0.378065	0.378105
2009	0.378065	0.378074	2021	0.378065	0.378114
2010	0.378065	0.378074	2022	0.378065	0.378124
2011	0.378065	0.378074	2023	0.378065	0.378134
2012	0.378065	0.378073	2024	0.378065	0.378146
2013	0.378065	0.378073	2025	0.378065	0.378158
2014	0.378065	0.378073	2026	0.378065	0.378172
2015	0.378065	0.378073	2027	0.378065	0.378186
2016	0.378065	0.378076	2028	0.378065	0.378202
2017	0.378065	0.378083	2029	0.378065	0.378219
2018	0.378065	0.378090	2030	0.378065	0.378238
2019	0.378065	0.378097			

If R&D investments in 28 industries would follow the recent increasing trend in the future in Korea, then the Gini coefficients will be increasing during 2008-2030 period as shown in table 3.   Therefore, R&D investments will have a negative effect on income distribution.   Also, we compare the Gini coefficients for counter-factual equilibrium with the benchmark equilibrium.

The Gini coefficient in benchmark equilibrium was 0.378065 in 2008. The Gini coefficients will increase as the R&D investments will follow the recent increasing trends in the future and the income distribution will be worse.

There are several reasons why R&D investments aggravate the income distribution of the economy.

In table 4, we show the trend of the Gini coefficients for total income during the period from 2008-2030.   The BAU represents the benchmark equilibrium, while SCN represents the counter-factual equilibrium in which R&D investments are assumed to increase the trend.   Also, DIF in table 4 denotes the difference between the two Gini coefficients for BAU and SCN. Thus, positive DIF implies that Gini coefficient has been increased and

Table 4   Decomposition of Total Income Distribution into
Labor Income and Capital Income

	(A) TOTAL GINI			(B) LABOR GINI			(C) CAPITAL GINI		
	BAU	SCN	DIF.	BAU	SCN	DIF.	BAU	SCN	DIF.
2008	0.378065	0.378074	**0.000009**	0.453587	0.453442	**-0.000145**	0.296879	0.296938	**0.000059**
2010	0.378065	0.378074	**0.000009**	0.453587	0.453442	**-0.000145**	0.296879	0.296938	**0.000059**
2015	0.378065	0.378073	**0.000008**	0.453587	0.453440	**-0.000147**	0.296879	0.296939	**0.000060**
2020	0.378065	0.378105	**0.000040**	0.453587	0.453435	**-0.000152**	0.296879	0.296941	**0.000062**
2025	0.378065	0.378158	**0.000093**	0.453587	0.453428	**-0.000159**	0.296879	0.296943	**0.000064**
2030	0.378065	0.378238	**0.000173**	0.453587	0.453419	**-0.000168**	0.296879	0.296947	**0.000068**

Notes: 1) BAU represents the benchmark equilibrium.   2) SCN represents the counter-factual
equilibrium.   3) DIF. = SCN - BAU.

aggravated income distribution.   We can easily observe that aggravation of total income distribution comes from aggravation of capital income as explained above.

4.4. Welfare Distribution Effect of R&D Investment

The effect of R&D investments on the welfare of 10 income class households in terms of equivalent variation is shown in table 5.   In table 5, we provide the difference in equivalent variation between income class i ($i = 1, \ldots, 10$) and the income class with lowest equivalent variation.

We may easily notice that R&D investments aggravate the welfare distribution in terms of equivalent variation.   The difference between the income distribution effect and the welfare distribution effect lies in the fact that the latter takes into account price change as well as income change while the former takes into account only income change due to R&D investments.

We will try to examine why R&D investments aggravate welfare distribution.   There are two propositions we want to suggest that explain why this is so: First, upper-income households consume more R&D intensive goods than lower-income households.   Second, the price of more R&D intensive products will decrease more than less R&D intensive products.

Table 5   Welfare Effect of R&D Investments in Terms of Equivalent Variation

(unit: billion Won)

Income Class	Equivalent Variation Difference
W01	1,597.1
W02	820.0
W03	0
W04	692.0
W05	444.1
W06	326.7
W07	2,107.9
W08	2,897.7
W09	5,579.2
W10	8,176.7

Note: E.V. Difference denotes the difference in equivalent variation between income class i (i = 1, …, 10) and the income class with lowest equivalent variation.

As a result, an increase in R&D investments increases the welfare of upper-income households more than lower-income households, since the upper can enjoy the benefit from lower price of R&D intensive products.   These results conform to the previous studies.

We examine our first proposition by computing the R&D intensities of ten consumption goods.

In table 6, index PI denotes the production good R&D intensity and index CI denotes the consumption good R&D intensity.   We examine our first proposition by computing R&D intensities of ten consumption goods.   In our model there are 28 production goods which are transformed into 10 consumption goods.   As expected, the electrical and electronic instrument industry (S13) shows as the most R&D intensive, and the precision industry (S14), the transportation industry (S15), the general machinery industry (S12) follow in that order. In terms of R&D intensity consumption good the traffic and communication good (C09) is most R&D intensive, the cultural recreation good (C08), the furniture and appliance good (C04), and the health and medical services (C06) follow in that order.

Table 6   R&D intensity of Consumption Goods

Production Good's R&D Intensity Index				Consumption Good's R&D Intensity Index	
Industry	PI (RD/Y)	Industry	PI (RD/Y)	Consumption Good	CI
S01	0.06019	S15	2.85077	C01	0.55187
S02	0.21061	S16	0.53259	C02	0.77978
S03	0.52092	S17	0.52261	C03	0.55427
S04	0.45393	S18	0.46752	**C04**	**5.21193**
S05	0.12571	S19	0.14086	C05	0.44739
S06	0.37480	S20	0.00428	**C06**	**2.91044**
S07	0.11061	S21	0.06390	C07	0.05706
S08	1.59354	S22	0.91989	**C08**	**6.51104**
S09	0.62981	S23	0.00013	**C09**	**6.74101**
S10	0.34382	S24	0.28596	**C10**	**3.52396**
S11	0.46631	S25	0.00000		
S12	2.09707	S26	0.00662	**Avg.**	*2.72887*
S13	6.98132	S27	2.35907		
S14	5.97723	S28	0.00000		

Note: Bold characters denote R&D intensive goods whose R&D intensity is bigger than the average R&D intensity.

Table 7   Proportion of Consumption Goods by Income Class: 2008

(unit: %)

	C01	C02	C03	**C04**	C05	**C06**	C07	**C08**	**C09**	**C10**	Avg.
W01	7.0	5.0	5.2	4.2	3.3	7.8	2.4	3.2	3.9	3.0	4.6
W02	7.8	8.8	7.3	5.4	4.7	7.3	4.3	5.0	5.8	4.4	6.3
W03	8.7	10.2	8.6	6.7	6.1	7.5	5.8	6.7	7.0	5.9	7.5
W04	9.2	9.5	9.5	7.1	7.1	8.1	7.5	7.8	8.4	7.0	8.3
W05	9.8	9.0	10.1	8.3	8.7	8.5	8.6	9.2	9.0	8.2	9.0
W06	10.3	9.4	10.6	9.7	9.8	9.0	10.5	10.4	10.2	9.1	9.9
W07	10.6	8.9	11.2	10.4	10.8	10.0	11.7	11.5	10.9	10.2	10.6
W08	11.2	9.6	11.6	11.5	13.1	11.9	13.9	13.1	12.2	11.9	11.8
W09	11.9	9.9	12.3	13.7	15.5	13.6	15.3	14.4	13.7	13.5	13.0
W10	13.4	19.8	13.5	23.1	20.9	16.3	20.0	18.7	18.9	26.7	19.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

In table 7, the proportion of consumption expenditure of income class i relative to whole consumption expenditures, where i=1, …, 10. Upper-income class households turn out to consume more R&D intensive products than the lower-income classes.

Table 8 shows the % change in prices of ten consumption goods during 2008-2030 periods.   Interestingly there are little differences among ten consumption goods in 2008.   As years go by, the magnitudes of price decreases will shrink.   In 2030, there are three R&D intensive goods whose price decreases are greater than the average.   There are also three less R&D goods whose price decreases are greater than the average.   So there is not a solid relationship between R&D intensity and price decrease of product.

We should consider all factors affecting household welfare.   Considering all those factors we conclude that R&D investments will benefit the upper income class households more than the lower income class households.

Table 8   Change in Price of Consumption Goods: 2008-2030

(unit: %)

	2008	2010	2015	2020	2025	2030
Food & Beverages	−0.5471	−0.5430	−0.5320	−0.5323	−0.5279	−0.5111
Residential Cost	−0.5417	−0.5280	−0.4867	−0.4466	−0.3870	−0.2949
Fuel Light & Water Charges	−0.5500	−0.5537	−0.5669	−0.5880	−0.6137	−0.6425
Furniture & Utensils	**−0.5196**	**−0.5170**	**−0.5124**	**−0.5090**	**−0.4971**	**−0.4674**
Clothing & Footwear	−0.5193	−0.5160	−0.5069	−0.4912	−0.4620	−0.4099
Medical Care	**−0.4760**	**−0.4675**	**−0.4392**	**−0.3576**	**−0.2350**	**−0.0581**
Education	−0.4662	−0.4559	−0.4212	−0.3228	−0.1761	0.0334
Culture & Recreation	**−0.5127**	**−0.5075**	**−0.4939**	**−0.4725**	**−0.4351**	**−0.3708**
Transportation and Communication	**−0.5186**	**−0.5172**	**−0.5170**	**−0.5231**	**−0.5234**	**−0.5088**
Others	**−0.5282**	**−0.5184**	**−0.4891**	**−0.4541**	**−0.3997**	**−0.3141**
Average	−0.5179	−0.5124	−0.4965	−0.4697	−0.4257	−0.3544

Note: Bold characters denote R&D intensive goods.

5. CONCLUSION

In this paper, we examine the effects of R&D investments on economic inequality in Korea using a dynamic Computable General Equilibrium model. In the model we classify household sector into 10 income groups and classify production sector into 28 industries. Policy simulation is designed to investigate the effect of R&D investments in 28 industries on income distribution during 2008-2030 period based on assumption that the R&D investments follow the recent trend.

Findings of policy simulation are as follows. Firstly, the R&D investments aggravate the income distribution, while they significantly improve the most major economic variables such as GDP, investments, consumptions during 2008-2030 periods. Thus, there exists a trade-off between efficiency and equity aspects of R&D. We try to explain the reason why R&D investments aggravate the income distribution and find that aggravation of income distribution comes from that of capital income distribution relative to labor income distribution.

Secondly, we examine the welfare effect of R&D investments based on the equivalent variation. As expected, R&D investments increase the welfare of upper-income households and decrease the welfare of lower-income households. We figure out that the upper income classes consume more R&D intensive goods than the lower income classes and furthermore the prices of R&D intensive goods will decrease more due to R&D investments. Empirically, however, there are mixed relations between R&D intensity and price decrease of consumption good. We should consider all factors affecting household welfare.   Considering all those factors we conclude that R&D investments will benefit the upper income class households more than the lower income class households.

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