The Korean Economic Review
Volume 36, Number 2, Summer 2020, 445-480.
DOI : 10.22841/kerdoi.2020.36.2.006

Policy Implications of Investment Rate Distributions in the Korean Manufacturing Sector*

Jinhee Woo**

A cross-sectional distribution of the investment rates of manufacturing establishments in Korea, based on the Mining and Manufacturing Surveys of 2011 through 2014, reveals a fat right tail and an asymmetry between positive and negative investment rates, reflecting the fixed cost of capital adjustment and the partial irreversibility of investment. This finding reveals that the aggregate responsiveness to the investment support policy will be greater during a boom than during a recession. A heterogeneous plant model designed to explain the cross-sectional distribution of investment rates observed in the data demonstrates that the response of aggregated investment to investment subsidy is 21.8% higher during a boom than during a recession. Our study also suggests that concentrating subsidies in establishments with small employment size will increase the investment inducement effect of the policy rather than provide equal subsidies for establishments of all sizes.

JEL Classification: E22, E32
Keywords: Investment, Fixed Cost, Partial Irreversibility

I. Introduction

Statistical samples from Korea's Mining and Manufacturing Surveys conducted from 2011 to 2014 show that 36.6% of surveyed establishments had investment rates (i.e., ratio of investment made in a given year to the existing capital stock at the start of that year) of at least 20%, while 24% had investment rates of 50% or higher. As for the asymmetry between positive and negative investment rates, 46.8% of surveyed establishments had investment rates of 10% or higher, while only 3.6% had investment rates below −10%. In the related literature, a fraction of plants with

Received: May 8, 2019. Revised: Sept. 28, 2019. Accepted: Nov. 27, 2019.
* This paper is drastically modified from Korea Institute of Public Finance's policy issue report (Woo, 2017). I thank the two anonymous referees for their helpful comments and suggestions. All errors are mine.
** Associate Fellow, Korea Institute of Public Finance, 336, Sicheongdaero, Sejong-si, 30147, Korea. Phone: 82-44-414-2341. Email: jinheew@gmail.com.

investment rates in excess of 20% and an asymmetry between percentage of establishments with positive investment rates and those with negative rates are often used as critical moments in identifying the degree of fixed cost of capital adjustment and partial irreversibility of investment, respectively.[1] Therefore, those cross-section moments observed in the Korean manufacturing sector indicate that fixed cost and partial irreversibility of investment may be significant factors shaping the distribution of investment rates in the Korean manufacturing sector.

The finding of the cross-sectional analysis of manufacturing establishments' investment rates also bears important implications for the business cycle dynamics of aggregate investment. The fixed cost factor means that establishments adjust their capital stocks only when sufficient changes in their profitability have accumulated. The aggregate investment response to a shock at a certain point in time will therefore depend upon the history of aggregate shocks until that point. In addition, due to asymmetry in the distribution of positive and negative investment rates caused by partial irreversibility, the shift in the density of establishments with high probabilities of adjusting their capital stocks will differ across booms and recessions.

The main purpose of this study is to evaluate quantitatively the validity of these theoretical implications in the Korean manufacturing sector. Specifically, I employ a heterogeneous plant model in which individual establishments make their optimal investment decisions in light of the fixed cost of capital adjustment and partial irreversibility of investment. The model is used to measure sizes of the fixed cost and partial irreversibility factors on the cross-sectional distribution of investment rates among Korean manufacturing establishments, as observed in the Mining and Manufacturing Surveys. By matching the cross-sectional distribution of individual establishments' investment rates in the steady-state model economy with moments observed in actual data, I find that, conditional on adjusting capital stock, a plant pays on average 1.02% of its annual output as the fixed cost of capital adjustment. Moreover, the discount rate on reselling capital goods, as a measure of partial irreversibility of investment, is 1.6%. That amount of fixed cost is twice as large as the corresponding statistics from the study of Khan and Thomas (2008), which uses a similar calibration strategy as this study and is likewise based on the investment rate distribution in the U.S. manufacturing sector.

I then analyzed how the effect of the investment subsidization policy would vary depending on the business cycle with a general equilibrium environment. This analysis indicates that the same investment subsidization program providing 0.2% of investment cost would induce 21.8% more investment if it was introduced during a boom than during a recession. The reason that some degree of state dependence survives under the general equilibrium environment is because the investment rate distribution of the Korean manufacturing sector is considerably more fat-tailed and

[1] Cooper and Haltiwanger (2006) term investment rate in excess of 20% as *investment spikes*.

skewed than that of the U.S. manufacturing sector, and implied adjustment frictions from the investment rate distribution are more significant than those from U.S. manufacturing. At the same time, consistent with the results from Khan and Thomas (2008), according to the partial equilibrium analysis, the general equilibrium forces come from household's consumption smoothing motive dampens around 60% of the state dependence of subsidy policy.

In an effort to find implications for designing an efficient investment subsidization program, I compare a program providing the same amounts of subsidies for all establishments with another program concentrating subsidies in establishments in the lower 70 percentile in terms of employment size. The analysis reveals that concentrating subsidies in establishments with relatively small employment size increases the investment inducement effect of subsidies by 1.7 times on impact when subsidies are provided. This happens because of the mean-reverting property of the idiosyncratic productivity process. Plants that have experienced a series of bad realizations of idiosyncratic shock currently have low levels of capital stock, and their idiosyncratic productivities have a tendency to revert to the mean level. The exact opposite holds true for plants in the high employment decile. Therefore, plants with small employment size have, on average, higher productivity relative to the current capital stock but never absolute productivity. The opposite also holds true for plants with large employment size. As a result, plants with small employment size are more responsive to the investment subsidy.

This study is related to literature that studies the role of micro-level adjustment costs in shaping aggregate investment dynamics. Basing their analysis on a heterogeneous plant model with a fixed cost of capital adjustment, Khan and Thomas (2008) conclude that movements in the equilibrium interest rates, which are decided by the smoothing behavior of household consumption, offset the impact of the cross-sectional distribution of investment rates on changes in economy-wide investment at turns of business cycles. During boom periods, if a higher fraction of plants simultaneously increase their investments, this would in turn increase the demand for final goods and raise interest rates. This general equilibrium effect leads some plants to cancel their investment plans. In addition, the resulting aggregate investment dynamics is almost identical with those from the convex cost of the capital adjustment model economy.

Bachmann et al. (2013) demonstrate that by calibrating the relative sizes of the fixed cost of capital adjustment and the general equilibrium effect through matching the relative time series volatilities of investment in three-digit sectors and non-farm private sectors, the quantitative size of the fixed cost of capital adjustment will grow much larger than that suggested by Khan and Thomas (2008). Fixed costs calibrated in this manner suggest that even in general equilibrium environments, where interest rates fluctuate according to business cycles, the volatility of aggregate investment will be significantly greater during a boom than in a recession (i.e., state dependence).

Winberry (2020) notes that contrary to the implication of one-sector RBC models, the real interest rates observed in U.S. data are countercyclical. By entering habit formation into the utility function of the representative household in Khan and Thomas' (2008) heterogeneous plant model, Winberry (2020) matches the cyclicality in the real interest rates of the model economy with actual data. He thus demonstrates that aggregate investment retains state dependence in general equilibrium environments owing to the fixed cost of capital adjustment.

While the central idea of this study is based on results from previous studies, it takes a closer look at the policy implications of micro-level adjustment frictions. Specifically, this study's significance lies in the fact that it confirms the state-dependent policy effect on aggregate investment through an analysis based upon a model economy reflecting the micro-level investment behavior of Korean manufacturing establishments. This study also quantitatively demonstrates that the aggregate investment inducement effect of the investment subsidization policy dependent on employment size is larger than that of the equal subsidization policy.

The remainder of this paper proceeds as follows. Section 2 provides an analysis of the cross-sectional distribution of investment rates among Korean manufacturing establishments by using annual cross-sectional data from Statistics Korea's Mining and Manufacturing Surveys. Section 3 describes the construction of a heterogeneous plant model, explicitly bounded by the two constraints on capital stock adjustment by individual establishments. Section 4 uses the model economy to measure sizes of the two constraints as operative on the cross-sectional distribution of investment rates among Korean manufacturing establishments. Section 5 extends the model to include the investment support policy of the government and verifies, via an impulse response analysis, whether the short-term investment inducement effect of the policy would vary with quantitative significance at different turns of the business cycle. This section also explores whether the policy design, either providing equal subsidies for all establishments or concentrating subsidies in establishments with relatively fewer employees, would also change its short-term investment inducement effect. Section 6 concludes the paper.

II. Distribution of Investment Rates in the Korean Manufacturing Sector

2.1. Data

Statistics Korea's Mining and Manufacturing Surveys present year-beginning balances, gross purchases, and gross sales of "buildings and structures," "machinery and furnaces," and "vehicles, ships, and transport machinery" owned by mining and manufacturing establishments with 10 or more employees each.[2] All the figures provided in the surveys are nominal values. Therefore, these figures need to be converted into real variables by using an appropriate deflator. As there are no official statistics available on deflators for capital stocks of Korean manufacturing establishments, different investment deflators of different categories of capital goods have been used to convert the nominal values of capital stocks and investments.[3] [4] The investment rate of individual establishments is thus defined as the difference between the gross purchase and gross sales of capital goods divided by the real year-beginning in capital stocks.

To determine whether the cross-sectional distribution of Korean manufacturing establishments' investment rates varied sporadically, survey samples were pooled into three groups: 2000 through 2006, 2007 through 2009, and 2011 through 2014. Of the manufacturing establishments with 10 or more employees each, those with missing information on employment and value added or capital stocks and those whose variables necessary for calculating investment rates were negative were excluded from the analysis. To minimize the effect of outliers, establishments in the top and bottom 1% in terms of investment rates each year were also excluded. The cross-sectional distributions of investment rates were then analyzed with respect to all three time periods.

[Table 1] Investment share of the manufacturing sector in the aggregate economy (2011–2014)

Category	Share
Gross Fixed Capital	34%
Facilities	48%
Facilities-Machinery	61%
Construction	17%
Intellectual Property	57%

Note: Statistics are calculated based on "Gross Capital Formation by Economic Activity and Type of Capital Goods" from Bank of Korea's Economic Statistics System.

This study is limited in that it analyzes the cross-sectional distribution of investment rates with respect to manufacturing establishments only, without the aid

[2] Until and during 2006, the survey provided data on establishments with five or more employees each.

[3] Panel data on individual establishments may enable the tracking of annual investments of individual establishments and apply the perpetual inventory method. However, the current study only utilizes cross-sectional data from the Mining and Manufacturing Surveys.

[4] The ratios of nominal values to real values concerning the gross capital formation of different types of capital goods (e.g., non-residential buildings, transportation equipment, machinery) as included in the Bank of Korea's National Account Data were used as investment deflators.

of micro-level data reflective of the entire industrial structure of the Korean economy. Nevertheless, the manufacturing sector accounted for 34% of the gross capital formation of all industries from 2011 through 2014. The sector likewise accounted for 48% of the gross facility investment across all industries. The manufacturing sector in Korea therefore plays a pivotal role in explaining economy-wide investment trends.

2.2. Distribution of Investment Rates in the Manufacturing Sector

Table 2 lists the number of establishments, investments, capital stocks, value added, and employment shares of different investment rate groups in the Korean manufacturing sector from 2011 to 2014. The distribution of establishments by investment rate can be described as follows.

First, whereas 47% of establishments had investment rates of 10% or higher, only 3.6% had investment rates of −10% or lower. In other words, an asymmetry exists between the number of establishments that increased their capital stocks during the observed years and the number that decreased theirs. Literature on the cost of capital adjustment points to the partial irreversibility of investment as one of the main causes leading to these asymmetries in investment rate distributions. Asymmetry of information (the lemons problem), specificity of capital goods, and other such characteristics of capital goods mean that those who purchase capital goods can resell them at reduced prices only, despite the quantity and quality of capital goods remaining the same. This phenomenon is known as the partial irreversibility of investing in capital goods. Given macroeconomic uncertainty and the uncertainty over their own profit prospects, and given this partial irreversibility (i.e., disparity between purchase price and reselling price) of their capital stocks, plants tend to hold onto their capital goods until their profitability improves rather than risk losses by reselling these goods at reduced prices. Accordingly, the percentage of establishments that resell their capital goods (i.e., that show negative investment rates) in the cross-sectional distribution of investment rates remains minimal at best.

Second, a significant proportion (24%) of all surveyed establishments had investment rates of at least 50%. This figure reflects the fact that establishments do not make incremental and minor adjustments to their capital stocks every period but rather make major investments periodically every few years. The fixed cost of investment involves decreases in output due to delays in production during the installation of new facilities as well as time and money spent on training employees on the use of the new facilities. Given this fixed cost of capital adjustment, the optimal behavior of plants when it comes to investment is not to even out their investment over time. Instead, they hold onto the same capital stocks to minimize the fixed cost of investment and make significant investments at once when necessary. That 24% of all surveyed manufacturing establishments had investment rates of 50% or more suggests there are significant fixed costs these establishments seek to avoid when investing in capital goods.

Third, nearly 50% of all surveyed establishments had investment rates between −10% and 10%, and their average investment rate was 1.7%. The majority of establishments belonging to this range of investment rates appear to have held off investing in capital goods. In the literature on capital adjustment costs, establishments that do not adjust their capital stocks in meaningful ways are considered to be in a state of "inaction." Inaction status is due to partial irreversibility and fixed cost. When an investment is partially irreversible, the plant decides not to adjust its capital stock insofar as the change that investment is going to make in its value (marginal q) remains lower than the purchase price and higher than the reselling price. When a fixed cost of capital adjustment exists, the establishment will postpone capital adjustment to the extent that the anticipated change in its value as a result of adjustment remains smaller than the fixed cost.

The three characteristics found in the cross-sectional distribution of manufacturing establishments' investment rates from 2011 through 2014 suggest that these establishments are faced with the partial irreversibility and fixed costs of capital adjustment.

Additionally, an examination of manufacturing establishments' shares of sector-wide capital stocks, employment, and value added in relation to their investment rates reveals that establishments with investment rates of 50% or higher occupy relatively higher shares of value added and employment compared to their shares of capital stocks. This suggests that establishments with high profitability or productivity substitute labor (with relatively smaller adjustment costs) for capital goods. They also undertake major investment in capital goods only when the disparity between the optimal level of capital goods they ought to possess and the level of capital goods they actually possess grows sufficiently large.

Figure 1 shows the cross-sectional distributions of investment rates among manufacturing establishments in three periods: 2000 through 2006, 2007 through 2009, and 2011 through 2014. It illustrates that the patterns regarding the percentage of establishments holding off capital adjustment, the asymmetry between capital stock-increasing establishments and capital stock-decreasing ones, and the relatively large percentages of establishments with high investment rates of 50% and above are not specific only to certain years but have been observed across these three periods. Nevertheless, note that the percentage of establishments holding off capital stock adjustment decreased steadily from the early 2000s to 2010 and later. Meanwhile, the percentage of establishments with investment rates of 50% or higher kept growing. These trends suggest that the exact magnitude of fixed cost and partial irreversibility of investment has been changing over time.

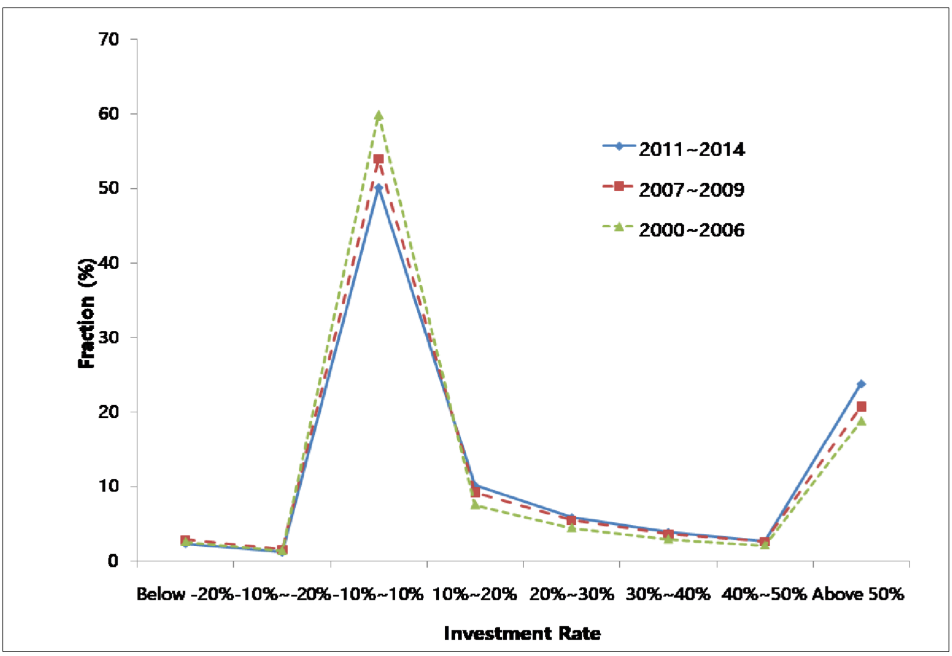
In Section 3, by using a heterogeneous plant model reflecting both fixed cost of capital stock adjustment and the partial irreversibility of investment, I gauge the respective contributions of these factors to explain the cross-sectional distribution of investment rates among Korean manufacturing establishments from 2011 through 2014.

[Table 2] Shares in the manufacturing sector by investment rate group (2011–2014 sample)

Investment Rate	Establishment	Investment	Capital	Value Added	Employment
Less than −20%	2.4%	−2.1%	2.4%	2.3%	2.4%
−20% to −10%	1.2%	−0.7%	1.5%	1.3%	1.3%
−10% to 10%	49.6%	10.0%	50.0%	46.1%	46.4%
10% to 20%	10.2%	12.7%	14.8%	14.5%	12.7%
20% to 30%	5.9%	10.7%	8.4%	8.4%	7.5%
30% to 40%	4.0%	8.8%	5.6%	5.8%	4.9%
40% to 50%	2.7%	6.3%	3.3%	3.6%	3.1%
More than 50%	24.0%	54.3%	14.0%	18.2%	21.7%

Note: Statistics are calculated using the pooled sample of 2011–2014.

[Figure 1] Investment rate distribution in the Korean manufacturing sector



Note: Each distribution is calculated using the pooled sample of corresponding periods.

III. Model Economy

This section describes the model economy that is used for quantitative analysis.

The model is a heterogeneous plant model in which individual plants make optimal investment decisions subject to both fixed cost of capital adjustment and partial irreversibility.

The model economy mainly consists of plants and households. Plants use labor and capital as production factors to produce goods that can be used for consumption and investment. Plants decide whether and how much to invest in capital with the goal of maximizing the present value of their profits. Households, on the other hand, decide how much to consume, work (provide labor), and own shares of plants toward maximizing their lifetime utility.

3.1. Production

The economy is composed by a unit mass of price-taking plants. Time is discrete, and at time t plant i produces a homogeneous final good by using a decreasing return to scale $(\alpha + \nu < 1)$ production function with labor (n_i) and predetermined capital stock (k_i):

$$y_{t,i} = \exp(z_t + x_{t,i}) k_{t,i}^{\alpha} n_{t,i}^{\nu} \tag{1}$$

where z and x_i denote aggregate and idiosyncratic productivity, respectively. Both productivity levels follow an AR(1) process in logs.

$$z_{t+1} = \rho_z z_t + \varepsilon_{z,t+1}, \quad \varepsilon_{z,t+1} \sim N(0, \sigma_z^2) \tag{2}$$

$$x_{t+1} = \rho_x x_t + \varepsilon_{x,t+1}, \quad \varepsilon_{x,t+1} \sim N(0, \sigma_x^2) \tag{3}$$

The investment decision of plants is subject to both partial irreversibility and fixed cost of capital adjustment. Partial irreversibility can be represented as a gap between the purchasing price and resale price of capital. Specifically, the purchasing price of capital is one unit of final good, but the resale price of capital is only $p_s (< 1)$ unit of final good. Then $1 - p_s$ measures the degree of irreversibility associated with the plant's investment decision. Adjustment of capital stock other than depreciation incurs a fixed cost that is denominated in terms of the final good. Fixed cost of capital adjustment is stochastic.[5] Every period, plant i draws that period's fixed cost $(\xi_{t,i})$ from time-invariant distribution $G(\xi)$. Realizations of fixed cost is i.i.d across time and plants. Following Khan and Thomas (2008) and Bachmann et al. (2013), I specify $G(\xi)$ as a uniform distribution on $[0, \bar{\xi}]$.

[5] In the data even after controlling plants' capital and productivity, variations in investment behavior still appear. To account for this pattern in a reduced form, the fixed cost of capital is usually introduced in a stochastic fashion. For a more detailed discussion, refer to Caballero and Engel (1999).

After observing the realization of aggregate productivity, idiosyncratic productivity, and level of fixed cost of capital adjustment, the plant makes employment and investment decisions to maximize the present value of expected profit. As there is no adjustment cost associated with employment, given the productivity and predetermined capital stock, the employment decision of a plant follows a static first-order condition.

Given that equilibrium factor prices depend on the plants' distribution over their capital stock and idiosyncratic productivity, this distribution also consists of the aggregate state variable and aggregate productivity level. I will denote plant distribution over (k,x) as μ. Next, plants are aware of the precise law of motion of plant distribution given their current aggregate state (z,μ): $\mu' = \Gamma(z,\mu)$

I can state the dynamic optimization problem of a plant by using individual and aggregate state variables. Let us denote $V(k,x;z,\mu)$ as the plant's value before the realization of the fixed cost of capital adjustment.

$$V(k,x;z,\mu) = \int_0^{\bar{\xi}} W(k,x,\xi;z,\mu)G(d\xi) \tag{4}$$

Then, conditional on the realized value of the fixed cost of capital adjustment, the maximized value of a plant is given as a discrete choice over positive investment, inaction, and negative investment.

$$\begin{aligned} W(k,x,\xi;z,\mu) = \max\{&W^p(k,x,\xi;z,\mu) - \xi, W^i(k,x,\xi;z,\mu), \\ &W^n(k,x,\xi;z,\mu) - \xi\} \end{aligned} \tag{5}$$

$$\begin{aligned} W^p(k,x,\xi;z,\mu) = \max_{\{i^p>0,n\}} \{&y(k,x,z) - w(z,\mu)n - i^p \\ &+ \mathbb{E}[d(z,z',\mu)V(k(1-\delta)+i^p, x'; z',\mu') \,|\, z,x]\} \end{aligned} \tag{6}$$

$$\begin{aligned} W^i(k,x,\xi;z,\mu) = \max_{\{n\}}\{&y(k,x,z) - w(z,\mu)n \\ &+ \mathbb{E}[d(z,z',\mu)V(k(1-\delta), x'; z',\mu') \,|\, z,x]\} \end{aligned} \tag{7}$$

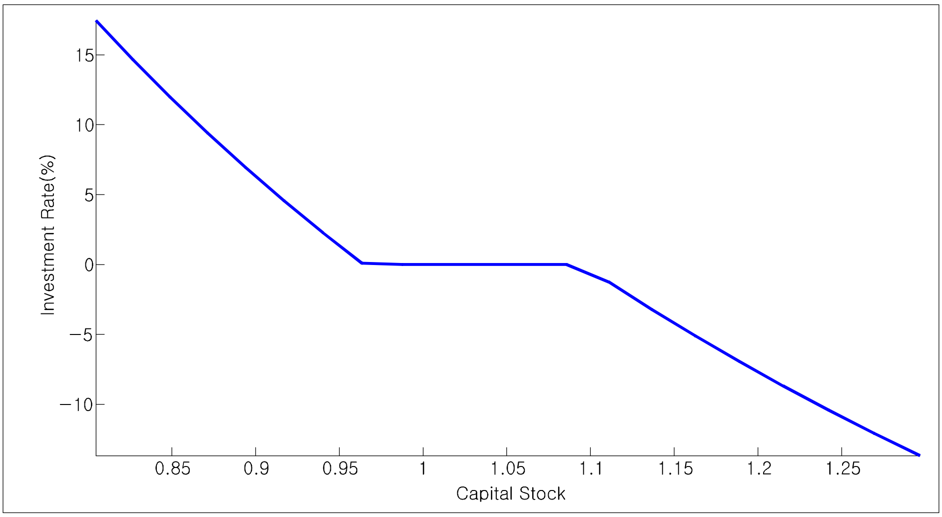
$$\begin{aligned} W^n(k,x,\xi;z,\mu) = \max_{\{i^n<0,n\}} \{&y(k,x,z) - w(z,\mu)n - p_s i^n \\ &+ \mathbb{E}[d(z,z',\mu)V(k(1-\delta)+i^n, x'; z',\mu') \,|\, z,x]\} \end{aligned} \tag{8}$$

where $w(z,\mu)$ and $d(z,z',\mu)$ respectively represent the spot labor market equilibrium wage and discount factor with which plants evaluate the next period's profit when current aggregate state is (z,μ) and next period aggregate state is $(z',\Gamma(z,\mu))$. These equilibrium objectives are jointly determined with the utility maximization problem of the household and the market clearing condition.

3.2. Optimal Investment Behavior

Before going into the household side of model economy, let us first explore how plants decide their optimal investment behavior when faced with the fixed cost of capital adjustment and the partial irreversibility of investment.

[Figure 2] Desired investment rate depending on current capital stock

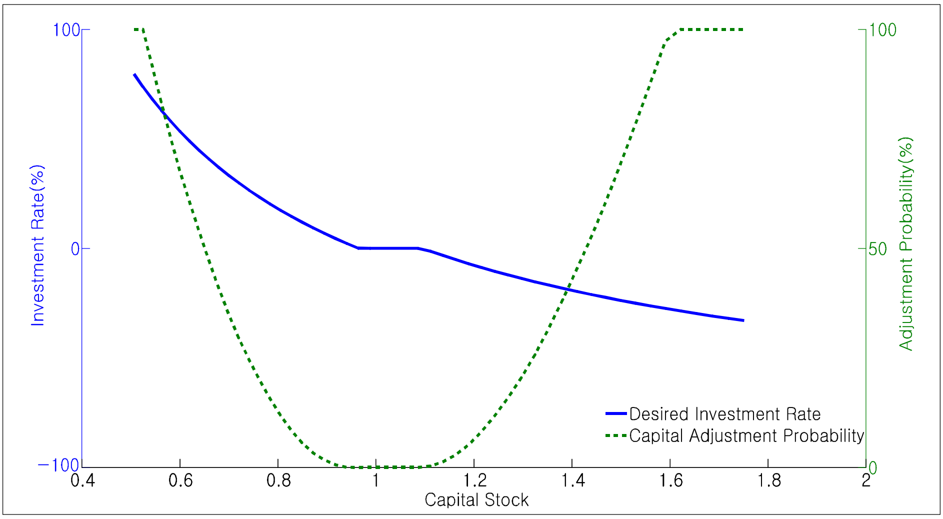


Note: This optimal decision rule is calculated using parameter values from the baseline calibration.

Figure 2 shows the present levels of capital stocks along the x-axis and investment rates that plants would choose if there were no fixed cost (desired investment rate) along the y-axis of plants at a median level of idiosyncratic productivity. Owing to the fixed cost of capital adjustment, not all plants actually adjust their capital stocks according to their desired investment rates. The discrepancy between purchase price and reselling price of capital goods (i.e., partial irreversibility of investment) also means that plants, whose expected marginal change in values as a result of capital adjustment falls somewhere between those two prices, have zero-desired investment rates irrespective of the fixed costs of capital adjustment involved.

Figure 3 illustrates plants' desired investment rates and their probabilities of capital adjustment under given levels of productivity and capital stocks. As the fixed costs of capital adjustment are given stochastically, the actual investment decision of plants is represented in terms of probability. Specifically, the actual capital adjustment of plants would match their desired investment rate with the probability that the fixed costs are less than the expected increases in the plant's values associated with capital adjustment. As expected increase in the value of a plant has a monotonic relationship with the absolute value of desired level of investment, so does the plant's capital adjustment probability. Therefore, in the equilibrium cross-sectional distribution of (actual) investment rates, the density of plants with relatively high investment rates increases.

[Figure 3] Desired investment rate and capital adjustment probability



Note: This optimal decision rule is calculated using parameter values from the baseline calibration.

3.3. Household

There is a unit measure of identical households that own all the plants in the economy. These households consume the final goods produced by plants and supply the labor necessary for the plants' production. Households are paid the market equilibrium wage per unit of labor they provide, but disutility arises from supplying labor. For each period, for a given real wage $w(z,\mu)$ and cum dividend share prices $\rho(k,x;z,\mu)$, $\rho'(k',x';\ z'\mu')$, households make decisions for consumption, labor supply, and share purchase (φ) to maximize the expected present value of lifetime utility.

$$H(\varphi;z,\mu)=\max_{\{c,n,\varphi'\}}\{\log c-\theta n+\beta\mathbb{E}[H(\varphi';z',\mu')\,|\,z]\} \tag{9}$$

$$\text{s.t.}\quad c+\int\int\rho'(k',x';z,\mu)\varphi'(k',x')dk'dx' = w(z,\mu)n+\int\int\rho(k,x;z,\mu)\varphi(k,x)dkdx \tag{10}$$

Given that households owns all the plants in the economy, plants discount future profits using the households' marginal rate of substitution across aggregate states.

3.4. Recursive Competitive Equilibrium

A recursive competitive equilibrium consists of (i) value functions V and H; (ii) policy functions k', n, C, and N; (iii) a wage w and state-contingent discount factors $d(z,z',\mu)$ and $\forall(z,z')$; and (iv) distribution of plants μ, such that:

1. V solves (4)–(8), and (k',n) represent the resulting policy functions for plants.
2. H solves (9)–(10), and (C,N) represent the policy functions associated with the household optimization problem.
3. Goods market clears the following:

$$\begin{aligned} C(z,\mu) = &\int y(k,x;z)d\mu(k,x) \\ &-\int (k'(k,x;z,\mu) - k(1-\delta))d\mu(k,x) \\ &-\int AC(k,x;z,\mu)d\mu(k,x) \end{aligned} \tag{11}$$

4. State-contingent discount factors coincide with the household's marginal rate of substitution across aggregate states:

$$d(z,z',\mu) = \beta \frac{C(z,\mu)}{C'(z',\Gamma(z,\mu))}, \quad \forall(z,z') \tag{12}$$

5. Intra-temporal Euler equation holds:

$$\theta C(z,\mu) = w(z,\mu) \tag{13}$$

6. The laws of motion for the distribution of plants are consistent with the plants' optimal investment behavior:

$$\begin{aligned} &\mu'(\mathcal{K},x') = \int_{\mathcal{B}(\mathcal{K};z,\mu)} H(x' \mid x)d\mu(k,x) \\ &\text{where } \mathcal{B}(\mathcal{K};z,\mu) = \{k \mid k'(k,x;z,\mu) \in \mathcal{K}\} \end{aligned} \tag{14}$$

The equilibrium for this economy is characterized by final goods market clearing condition and inter-temporal and intra-temporal optimization conditions of the households. The final goods market clearing condition states that the demand for final goods composed by households' consumption, aggregated plants' investment, and adjustment cost associated with plants' capital adjustment should match aggregated plants' supply of final goods. For households' inter-temporal condition to be satisfied, state-contingent discount factors coincide with households' marginal rate of substitution. For a given equilibrium consumption, spot labor market equilibrium wage satisfies intra-temporal optimization condition.

As the distributions of plants' capital stocks and productivity levels decide the equilibrium consumption, in the analysis for business cycle fluctuations, it is necessary to forecast changes in the equilibrium consumption due to aggregate productivity shocks by using a method like the one in Krusell and Smith (1998).

IV. Calibration

4.1. Calibration Results

The time discount rate (β) for the household in our model economy is 0.969, which is based on the average real annual interest rate of 3.2% in Korea from 2010 to 2015. The depreciation rate (δ) of capital stocks is 12%, a weighted average of the depreciation rates of 3.5% applied to buildings and structures and 17.9% applied to machinery, ships, and transportation equipment in Cho (2012). Furthermore, the weights of different categories of capital stocks in the Korean manufacturing sector is calculated from a 2011–2014 sample of Korea's Mining and Manufacturing Surveys. The degree of returns to scale in the production function is 0.79, as per Han and Woo (2017).

The share of capital in the production function $(\frac{\alpha}{\alpha+\nu})$ is 30%, which is obtained by first estimating costs of capital and labor as provided in the Mining and Manufacturing Surveys and then using the share of the capital cost in that sum. For this purpose, labor cost is defined as the sum of gross wages with gross fringe benefit expenses. As for self-employed and unpaid family business workers, total wages and number of paid workers in businesses are used to estimate the average wages, and self-employed and unpaid family business workers are assumed to have been paid average wages. The user cost of capital is estimated in light of the depreciation rates of different types of capital goods and real interest rates, as attempted by Oh (2014).

The fixed cost of capital adjustment $(\overline{\xi})$, partial irreversibility of investment (p_s), and stochastic process of idiosyncratic productivity shocks in individual plants (ρ_x, σ_x) are jointly determined by matching the cross-sectional distribution of individual plants' investment rates. In addition, size of disutility from labor supply is determined by matching the working hours of the representative household with the corresponding measure in data.

The moments chosen for the cross-sectional distribution analysis of investment rates are percentages of plants with investment rates of 50% or above, 30% to 50%,

−10% to −20%, and −20% and below. Identifying with exactitude the threshold investment rate at which plants do not significantly adjust their capital stocks is difficult. Thus, those studying capital adjustment costs typically focus on how many plants are located at either extremes of investment rate distribution as well as the size of the asymmetry between plants with positive investment rates and those with negative rates. In particular, the percentage of plants with investment rates of 20% or above is often associated with the size of fixed cost, while asymmetry between positive and negative investment rates helps with gauging the partial irreversibility of investment. While the method used in Cooper and Haltiwanger (2006) is not identical to the one used here, the distribution of investment rates among Korean manufacturing establishments from 2011 through 2014 shows greater percentages of establishments at the extremes as well as a stronger asymmetry between positive and negative investment rates than their U.S. counterparts. Therefore, investment rates must be divided into more ranges as part of the moment-matching process.

The moments chosen for analysis of the business cycle dynamics are the AR(1) coefficients and relative volatility of the HP-filtered aggregate fixed capital formation (real and annual) to HP-filtered real GDP from 1990 through 2018, as indicated in the Bank of Korea's National Account. The parameters of the model economy most closely related to these moments are persistency and volatility of aggregate productivity shocks. In the general equilibrium analysis, because of the consumption smoothing behavior of households, the relative sizes of fixed cost and partial irreversibility of investment do not critically affect the AR(1) coefficient of the model implied aggregate investment series. Hence, at first, the size of the each component of investment friction is solely calculated by matching the cross-sectional distribution of investment rates. Next, persistency and volatility of aggregate productivity shocks are calculated with a 1500 period of business cycle simulation of the model economy using the algorithm by Krusell and Smith (1998).

Tables 3 and 4 show the parameters chosen for our model economy and the resulting target moments from the model economy, respectively. Even though there is room for improvement, the model economy adequately captures the asymmetry between positive and negative investment rates and the relatively large percentage of establishments adjusting their capital stocks through major actions, the two important factors of the actual cross-sectional distribution of investment in the Korean manufacturing sector. While the model economy and given data closely match for most investment ranges, the model economy cannot generate enough plants with investment rates of 50% or above. This finding appears to reflect the fact that the percentage of plants with investment rates of 50% or above decreases when plants are concerned with losses they would incur in reselling their capital goods in the future given the partial irreversibility of investment.

The persistence (AR(1) coefficient) of the productivity shock of individual plants is 0.8, similar to the 0.757 to 0.814 estimated with respect to U.S. manufacturing plants in Foster et al. (2008). Conditional on adjusting capital stock, on average, plants pay 1.02% of their annual output as the fixed cost of capital adjustment. This amount is the intermediate value between 0.5% in Khan and Thomas (2008) and 3.6% in Bachmann et al. (2013).[6] The discount rate on the purchase price that plants would experience when reselling their capital goods (i.e., partial irreversibility of investment) is 1.6%. This is comparable to the discount rate of 1.9% for U.S. manufacturing plants as estimated in Cooper and Haltiwanger (2006).

[Table 3] Parameter values for the baseline economy

Parameter	Value	Description
β	0.97	discount factor
δ	0.12	depreciation rate
$\alpha+\nu$	0.79	return to scale
$\frac{\alpha}{\alpha+\nu}$	0.30	share of capital
ξ	0.009	upper bound for fixed cost
p_s	0.984	resale price of capital
θ	2.22	disutility from labor supply
ρ_x	0.80	persistence of idiosyncratic shock
σ_x	0.08	S.D. of idiosyncratic shock
ρ_z	0.90	persistence of aggregate shock
σ_z	0.01	S.D. of aggregate shock

[Table 4] Result of endogenous calibration

Moment	Target	Model
Fraction of plants whose $\frac{i}{k} \leq -20\%$	2.4%	2.5%
Fraction of plants s.t. $-20\% \leq \frac{i}{k} \leq -10\%$	1.2%	1.2%
Fraction of plants s.t. $30\% \leq \frac{i}{k} \leq 50\%$	6.7%	6.3%
Fraction of plants whose $\frac{i}{k} \geq 50\%$	24.0%	15.9%
Hours worked	0.33	0.31
AR(1) coefficient of aggregate investment	0.42	0.43
S.D. of agg. Investment/S.D. of GDP	3.2	3.0

To understand why both fixed cost and partial irreversibility of capital adjustment are needed to match the cross-sectional distribution of investment rates, I compare the baseline model (i.e., the model with parameters that most closely match the distribution of investment rates observed in the data) with re-calibrated

[6] Refer to Table 4 of Bachmann et al. (2013).

models from which either irreversibility of investment or fixed cost of capital adjustment has been removed (Figures 4 and 5).

Figure 4 shows the performance of the model economy with only the fixed cost of capital adjustment. For this exercise, I set the resale price of capital (p_s) at 1 and re-calibrated other endogenously chosen parameters. With a fixed cost of capital adjustment, plants with low productivity prefer to depreciate their capital stock to disinvestment, which incurs paying fixed cost. Thus, the model economy with only fixed cost can still generate some degree of asymmetry between positive investment rates and negative ones. This is why Khan and Thomas (2008) match investment rate moments from the U.S. manufacturing sector with only the fixed cost of capital adjustment. However, in the Korean manufacturing sector, the observed asymmetry between positive investment rates and negative ones is far more severe than that from the US. In the model economy without partial irreversibility of investment, the calibration process seeks less persistent and less volatile idiosyncratic productivity processes to prevent generating drastic negative investment spikes. However, as plants are no longer restricted by discounts on the reselling prices of their capital stocks, the percentage of plants reducing their capital stocks (i.e., showing negative investment rates) increases. The asymmetry between plants with positive investment rates and those with negative rates therefore narrows compared to that of the baseline model economy. In other words, the degree of asymmetry between positive investment rates and negative ones observed in the Korean manufacturing sector cannot be fully generated by the model economy with only the fixed cost of capital adjustment.

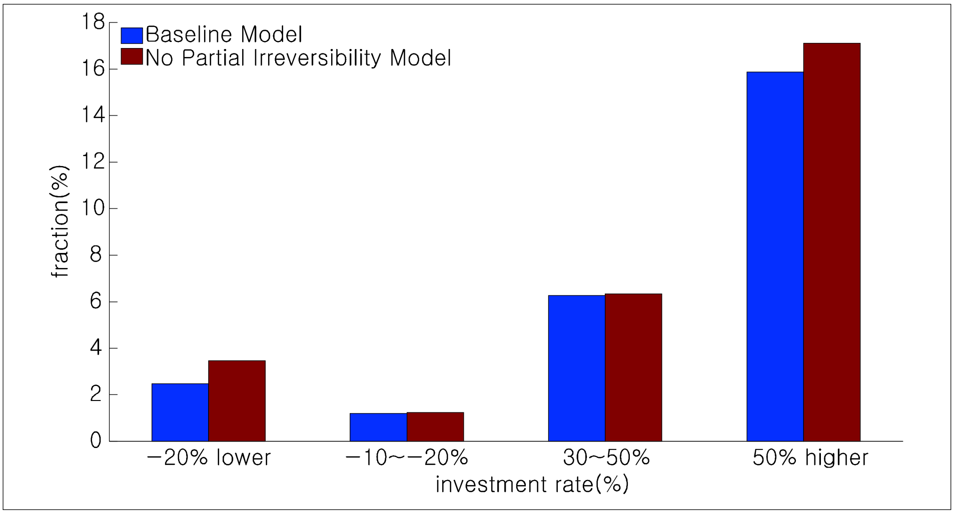
[Table 5] Parameter values for various economies

Parameter	Baseline	No PI	No FC
ξ	0.009	0.01	0
p_s	0.984	1	0.97
ρ_x	0.80	0.78	0.85
σ_x	0.08	0.07	0.08
θ	2.22	2.07	2.21

Note: PI = Partial irreversibility, FC = Fixed cost.

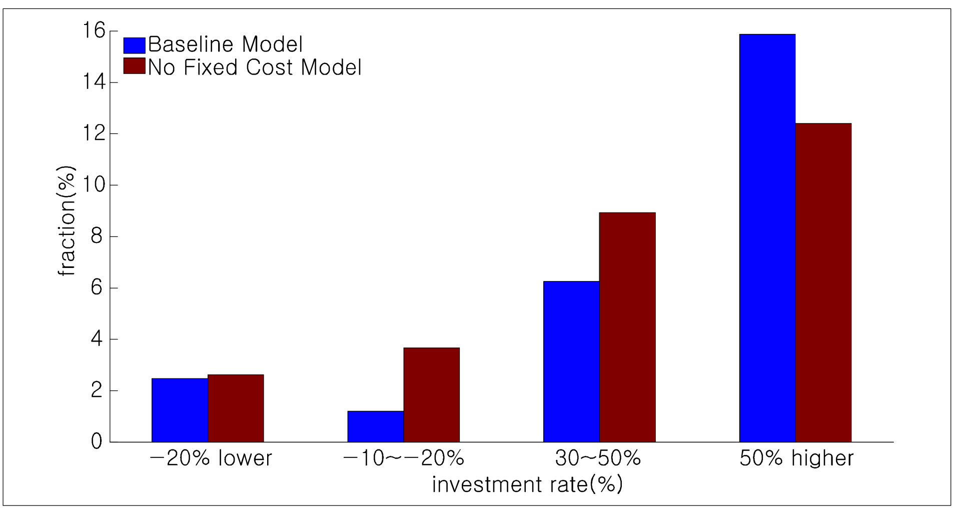
Figure 5 shows the cross-sectional distribution of investment rates from the model economy without fixed cost of capital. The optimal investment behavior of plants switches to making relatively smaller investments with higher frequency. The percentage of plants with investment rates of 50% or above decreases, whereas the percentage of those with rates of 30% to 50% increases. This result suggests the necessity of including detailed investment rate ranges to identify the size of the fixed cost of capital adjustment from the cross-sectional distribution of investment rates.

[Figure 4] Changes in investment rate distribution without partial irreversibility



Note: "No Partial Irreversibility Model" represents the model with $p_s = 1$ and where other endogenously chosen parameters are re-calibrated.

[Figure 5] Changes in investment rate distribution without fixed cost of capital adjustment

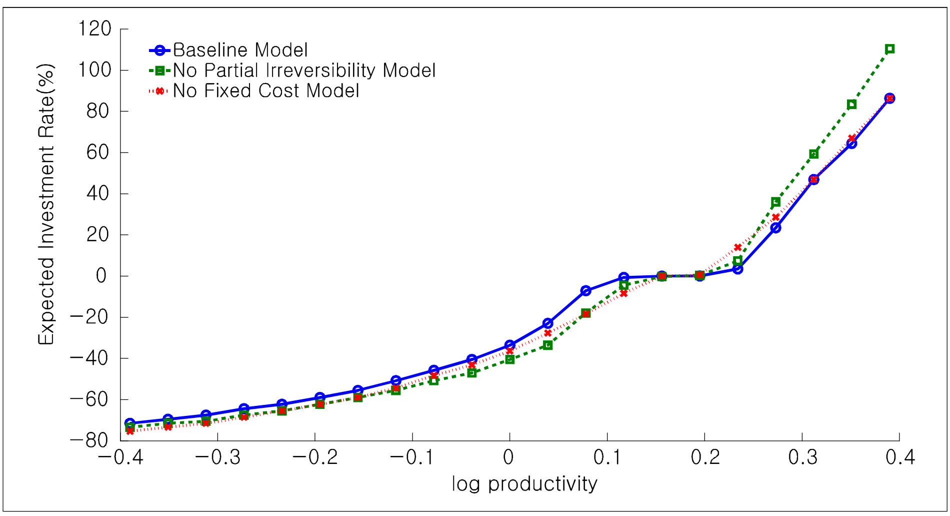


Note: "No Fixed Cost Model" represents the model with $\bar{\xi} = 0$ and where other endogenously chosen parameters are re-calibrated.

4.2. Role of Adjustment Costs in Determining Allocation Efficiency

With the presence of plant level uncertainty, both partial irreversibility and fixed cost of capital adjustment prevent plants from immediately adjusting their capital stock toward a frictionless optimal level. Figure 6 shows how optimal investment behavior depending on idiosyncratic productivity (for fixed level of capital) changes when either of these adjustment frictions are removed from the baseline economy.[7] As either friction is removed, the expected investment rate (desired investment rate multiplied by adjustment probability) increases for the plant with higher than median productivity, and the expected disinvestment rate decreases for the plant with lower than median productivity. This pattern is more evident when partial irreversibility is removed. Given the inherent uncertainty in productivity levels of individual plants, removing the irreversibility of investment means that plants are now free from worries of suffering losses when reselling their capital goods in the future. Therefore, without irreversibility, disinvestment associated with low productivity and investment associated with high productivity both become more responsive.

[Figure 6] Expected investment rate depending on productivity



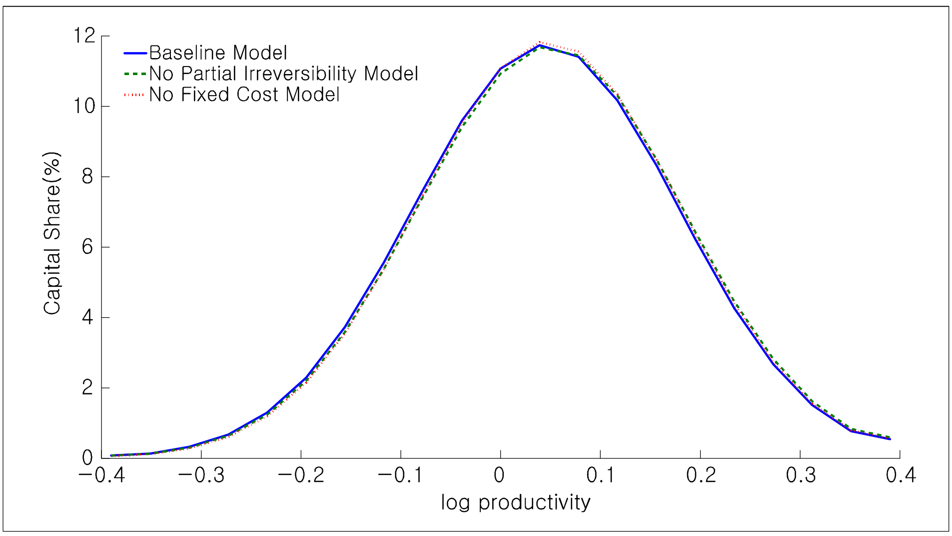
Note: "No Partial Irreversibility Model" and "No Fixed Cost Model" represent the model with $p_s = 1$ and the model with $\bar{\xi} = 0$, respectively, with all the other parameters kept the same with the baseline model.

Through their effect on optimal investment behavior, both adjustment frictions eventually affect the capital and output share of plants with different idiosyncratic productivity levels. Figure 7 shows the shift in capital share distribution over idiosyncratic productivity from a steady state of baseline model economy as each adjustment friction is removed. As a result of shifts in capital share distribution when partial irreversibility is removed in the new steady-state equilibrium, capital

[7] For this exercise, I only varied parameter for resale price or fixed cost of capital with keeping other parameters are fixed at baseline model economy.

share weighted average productivity of plants increases 0.37% and, without fixed costs, increases 0.31% from the steady-state equilibrium of the baseline model economy. Consequently, removing partial irreversibility and fixed cost increases output share weighted average productivity of plants by 0.19% and 0.14%, respectively. Thus in the Korean manufacturing sector, if hypothetically the irreversibility of investment or fixed cost of capital adjustment is fully removed, then in the long-run, a corresponding amount of efficiency gain is to be expected. However, as both adjustment frictions are not correlated with the productivity of individual plants, the quantitative effect of adjustment frictions on allocation efficiency is limited. This result resembles the conclusion of Restuccia and Rogerson (2008) that only productivity-correlated idiosyncratic distortions have quantitatively meaningful effects on measured total factor productivity (TFP).

[Figure 7] Shift in capital share distribution over idiosyncratic productivity



Note: "No Partial Irreversibility Model" and "No Fixed Cost Model" represent the model with $p_s = 1$ and the model with $\bar{\xi} = 0$, respectively, with all the other parameters kept the same with the baseline model.

V. State-dependent Effect of Investment Subsidy

The ultimate question this study intends to answer is how cross-sectional distribution of investment rates in Korea affects the dynamics of aggregate investment in a business cycle frequency. In other words, the key question is whether partial irreversibility and fixed cost of investment faced by individual plants are crucial factors that explain the business cycle dynamics of aggregate investment.

Of particular interest is whether the same investment support policy would exert effects of the same size on inducing investment when the economy is either in a boom or in a recession.

The asymmetry of plants' distribution between positive investment rates and negative ones, together with state-dependent adjustment behavior caused by fixed cost, means that the density of plants with high probabilities of making positive investment increases during a boom. As a result, the aggregate responsivity to policy incentives for investment would be much greater during a boom than in a recession. To test this hypothesis quantitatively, using the model economy described in Section 3, let us analyze how the investment support policy would affect aggregate investment differently with the business cycle fluctuations caused by aggregate productivity shock. Using the fact that investment probabilities vary by the employment sizes of individual plants, I investigate policy design of investment subsidy as well.

5.1. Accuracy of Forecasting Rules

Before delving into the results of policy analysis, let us briefly discuss the accuracy of forecasting rules used to implement the Krusell–Smith method. I solved the optimization problems in terms of a marginal-utility-transformed Bellman equation following Khan and Thomas (2008) and the approximate distribution of plants by aggregate capital stock. Therefore, I need the forecasting rules for (i) the log-linear law of motion for the aggregate capital stock and (ii) the marginal utility of consumption. To ensure that the goods market is actually cleared in each period along the business cycle simulation, I follow a two-step procedure suggested by Krusell and Smith (1998). That is, forecasting rules are only used when calculating perceptions of future prices, and current period market clearing consumption come from an explicit market clearing condition. Equations (15) and (16) show the resulting forecasting rules.

$$\ln K' = -0.061 + 0.735 \ln K + 0.475 \ln Z \tag{15}$$

$$\ln P = 0.801 - 0.370 \ln K - 0.731 \ln Z \tag{16}$$

where P is the marginal utility of consumption.

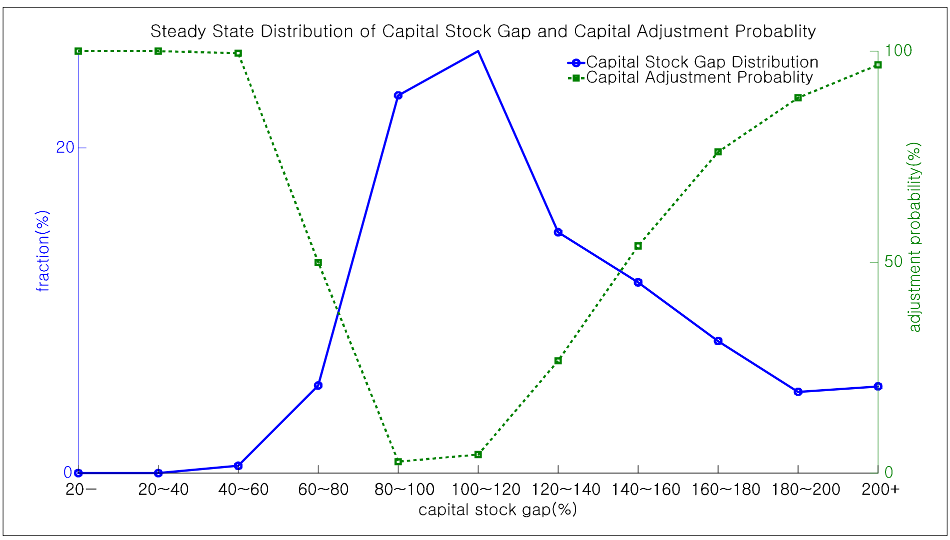
Table 6 provides various accuracy measures of forecasting rules. I show both R^2 measure and statistics suggested by den Haan (2010). While R^2 is only concerned about a one-period ahead forecast, den Haan (2010) statistics assess the accuracy of forecasting rules by comparing whole sequences of *actual equilibrium* variables and sequences of variables that are generated by rolling-over forecasting rules. The terms "max den Haan" and "average den Haan" mean maximum and average absolute value differences, respectively, between two sequences relative to the values of the *actual equilibrium* sequence. The diagnostics reported in Table 6 indicate that forecasting error in the business cycle simulation is negligible.

[Table 6] Accuracy measures of forecasting rules

Variable	R^2	max den Haan	average den Haan
$\ln K'$	0.99973	0.39%	0.09%
$\ln P$	0.99998	0.13%	0.03%

5.2. Effect of Aggregate Shock on the Distribution of Capital Stock Gap

[Figure 8] Steady-state distribution of capital stock gap and capital adjustment probability



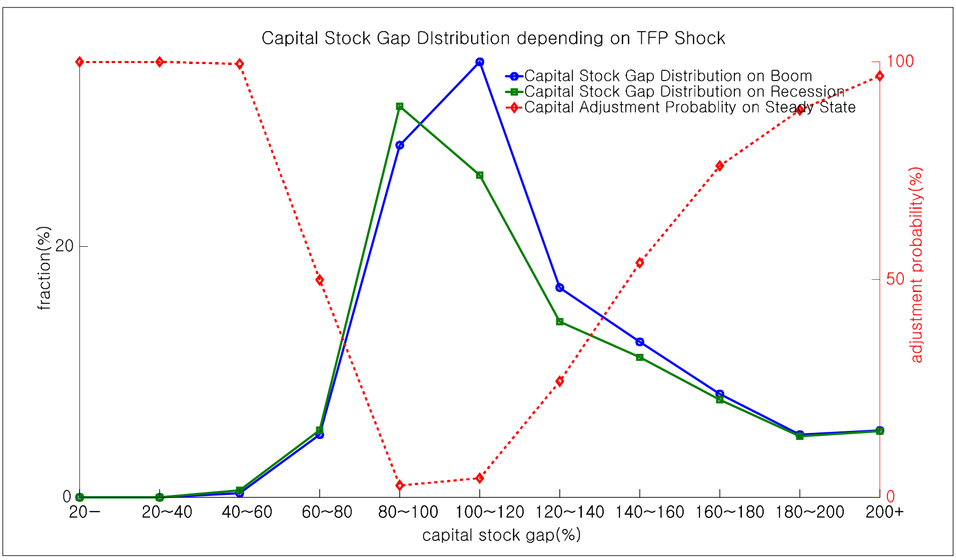
Note: The solid line represents the distribution of capital stock gaps among manufacturing plants in the steady-state equilibrium, while dashed lines represent the average probabilities with which plants in a certain capital stock gap range would adjust their capital stocks according to targets.

The probability of a plant actually attempting to adjust its capital stock would be determined by the ratio between the amount of capital stock it wishes to have the next period (the capital stock the plant would have next period if there were no fixed cost) and the remaining post-depreciation capital stock it would have at the end of the current period. Let us refer to this ratio as the "capital stock gap." Figure 8 shows the distribution of capital stock gaps among plants in the steady-state model economy and the average probabilities with which plants in a certain capital stock gap range would adjust their capital stocks according to their targets.

Figure 8 shows an asymmetry between the percentage of plants with capital stock gaps of 100% or higher (i.e., plants that have less capital stocks than they need) and the percentage of plants with capital stock gaps of less than 100% (i.e., plants that have capital stocks in excess of what they need). This asymmetry can be understood as mirroring the asymmetry between the percentage of plants with positive investment rates and of those with negative rates in the cross-section investment rate of steady-state equilibrium.

The figure likewise reveals that the probability with which plants would adjust their capital stocks to their target level is not constant but rather increases more as plants depart from a capital stock gap of 100%. This implies that the greater the percentage of plants with capital stock gaps of 140% or higher, the more effective the investment support policy would be.

[Figure 9] Adjustment probability weighted capital stock gap distribution depending on aggregate status



Note: The solid line represents the distribution of adjustment probability weighted capital stock gaps when the economy is hit by *positive* two-standard deviation aggregate productivity shock, while the dashed lines represent the distribution of adjustment probability weighted capital stock gaps when the economy is hit by *negative* two-standard deviation aggregate productivity shock. The dotted line represents the average probabilities with which plants in a certain capital stock gap range would adjust their capital stocks according to their targets in the steady-state equilibrium.

Given the asymmetrical distribution of capital stock gaps, positive and negative productivity shocks to the aggregate economy would exert considerably different effects on that distribution. Figure 9 shows how the distribution of capital stock gaps would change from its steady state, accounting for variations in equilibrium consumption, while the TFP of the aggregate economy either increases or decreases by two standard deviations.[8] Given that average adjustment probabilities in a certain capital stock gap range also deviate from their steady-state value, I multiplied fractions in each category by the ratio of average adjustment probabilities in either boom or recession to the average adjustment probabilities in steady state.

The aggregate effect of investment support policy would vary depending on how high the percentage of plants with capital stock gaps of 140% or more is on the capital stock gap distribution. During a boom, even after considering the general equilibrium forces, the density of plants with relatively larger capital stock gaps is higher than during a recession. Hence, investment subsidies are likely to be more effective during a boom.

5.3. Impulse Response Analysis

I can use impulse response analysis to compare quantitatively whether and how much the investment-inducing effect of investment support policy would differ across the aggregate TFP shock-driven boom and recession.

At time 0, before TFP shock is realized, distributions over capital stock and idiosyncratic productivity levels of individual plants are given as its steady state. A shock is exerted at time 1 to either increase or decrease aggregate productivity by two standard deviations. Over time, aggregate productivity would return to its steady-state level according to its own AR(1) coefficient. If policy subsidies of 0.2% of investment cost (magnitude of investment multiplied by the price of capital, which is equal to one unit of final goods) were to be provided for plants opting to increase their capital stocks at time 1 when aggregate productivity shock occurs, would aggregate investment response change?[9] Would the same subsidies have the same effect whether the shock increased aggregate productivity (i.e., a boom) or decreased it (i.e., a recession)? Specifically, the subsidy is only provided at period 1 in an unexpected manner and financed by a lump-sum tax from households. With this subsidy policy, the optimization problem of the plant conditional on positive investment (Equation [6]) at period 1 is modified as follows:

$$\max_{\{i^p>0,n\}} \{y(k,x,z) - w(z,\mu)n - (1-sb)i^p \\ + \mathbb{E}[d(z,z',\mu)V(k(1-\delta)+i^p, x'; z', \mu') \,|\, z,x]\} \tag{17}$$

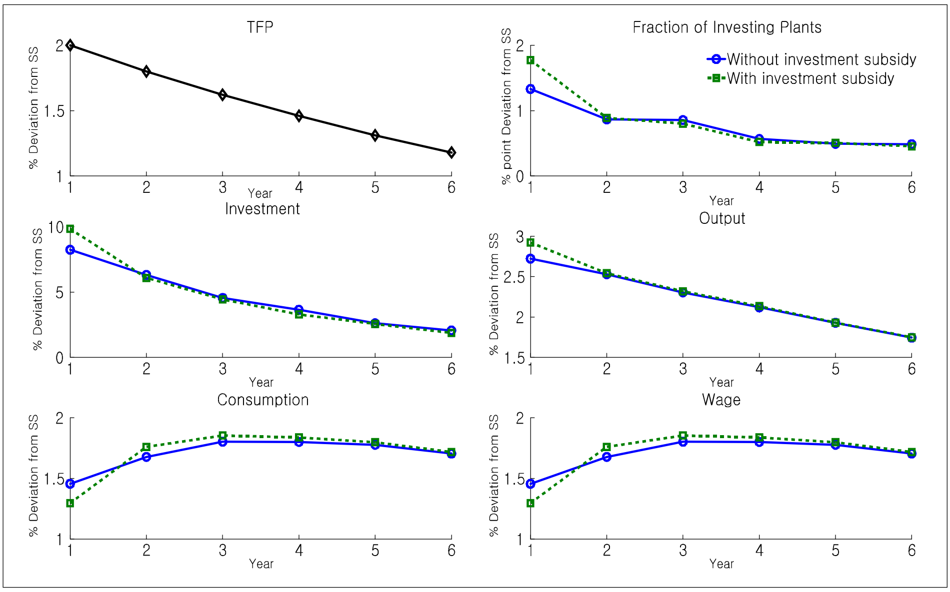
[8] To streamline the visualization of the state-dependent effect, I used two standard deviations of aggregate shock instead of the more standard one standard deviation shock.

[9] I chose 0.2% as the magnitude of subsidy to show that this policy exercise does not require an unrealistically huge amount of investment subsidy. At the same time, this subsidy magnitude streamlines the visualization of impulse response that compares dynamics with and without investment subsidy.

where *sb* is the subsidy per unit investment

Figures 10 and 11 illustrate the impulse response of aggregate variables to aggregate productivity increase (boom) and decrease (recession), respectively. Solid lines (investment without subsidies) represent dynamic movements of the variable in response to the aggregate productivity shock without investment subsidy, while the dashed lines (investment with subsidies) represent movements of the variable in response to both aggregate productivity shock and investment subsidies at period 1.

[Figure 10] Effect of investment subsidy when the economy is hit by positive TFP shock

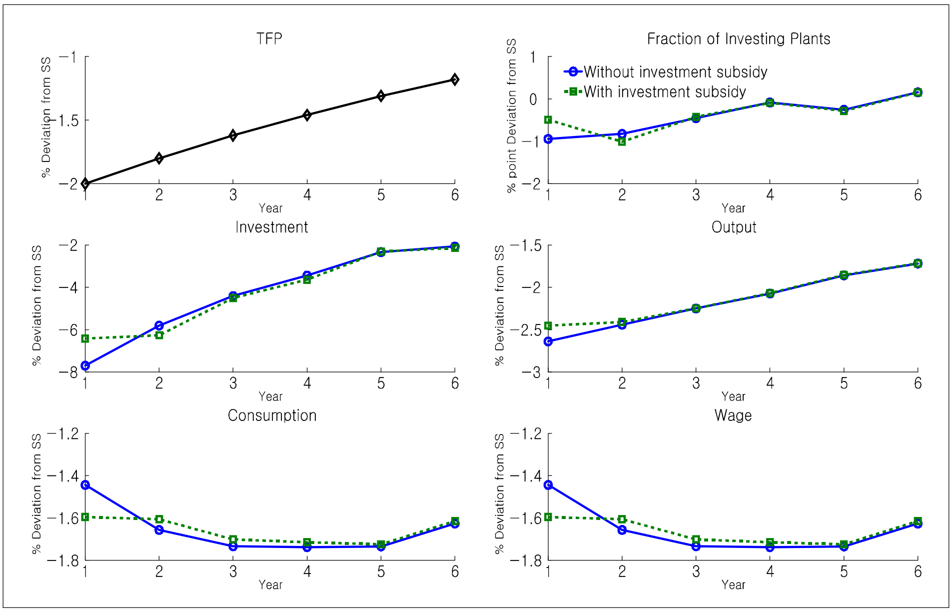


Note: The solid lines (investment without subsidies) represent dynamic movements of the variable in response to the aggregate productivity shock without investment subsidy, while the dashed lines (investment with subsidies) represent movements in the variable in response to both aggregate productivity shock and investment subsidies at time 1.

The dynamic response of aggregate investment and responses in extensive margins of investing plants depicts how the response of aggregate investment parallels the percentage changes of investing plants.

As for the effect of the investment support policy, the number of investing plants increases in the same period when the policy is introduced, leading to an overall increase in aggregate investment. However, by the second or third period, the percentage of investing plants and aggregate investment decreases further than would have been the case in the absence of the investment support policy. This is because the introduction of the subsidy policy leads plants to undertake their investment in the first period, even though their original plan was to invest in either the second or third period. Another reason for this is general equilibrium forces generated from the subsidized firms lead to the hiring of relatively more labor starting from period 2.[10]

[Figure 11] Effect of investment subsidy when the economy is hit by negative TFP shock



Note: The solid lines (investment without subsidies) represent dynamic movements of the variable in response to the aggregate productivity shock without investment subsidy, while the dashed lines (investment with subsidies) represent movements in the variable in response to both aggregate productivity shock and investment subsidies at time 1.

As in the typical RBC model, consumption shows a hump-shaped response. Especially, with the introduction of investment subsidy, the equilibrium path of consumption becomes steeper, which leads to higher risk-free rates and mitigates the effects of investment subsidy on shifts in investment timing. Given our specification of indivisible labor, the response of equilibrium wage parallels that of consumption.[11] On the impact of TFP shock, because consumption response dampens with investment subsidy so does equilibrium wage. As a result, on impact of a shock, output with investment subsidy can expand further compared to the case without subsidy.

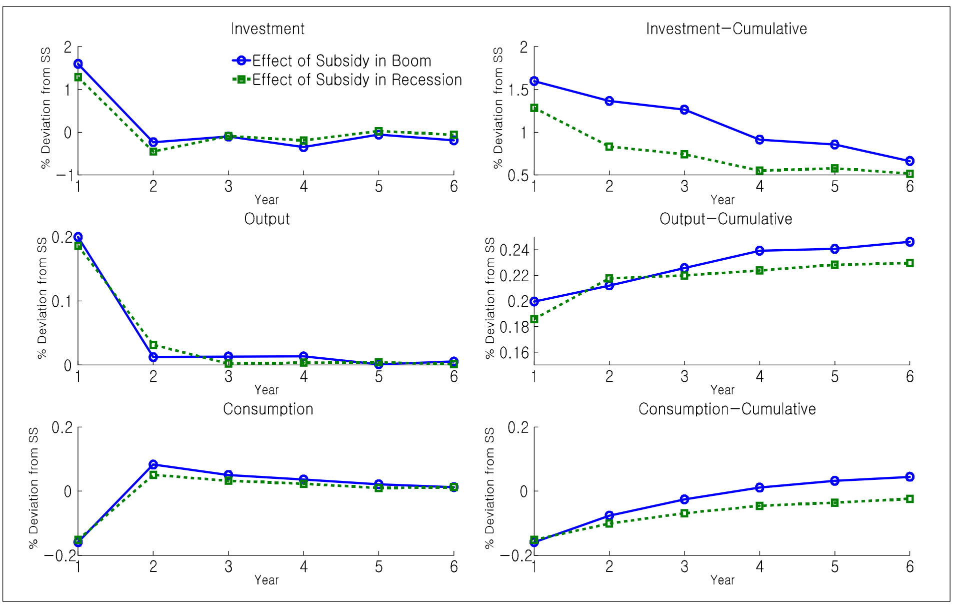
Figure 12 shows how dynamic responses of aggregate variables differ under the investment support policy, depending on whether aggregate productivity increased or decreased. On impact, the investment support policy increases aggregate

[10] Thank you for the anonymous referee for pointing out this mechanism.

[11] The indivisible labor specification is commonly used in the literature of heterogeneous plant model. For example, see Khan and Thomas (2008) and Bachmann et al. (2013).

investment by 21.8% (0.3 percentage point) more during a boom than in a recession. Such a policy, when coupled with a boom, also increases the cumulative aggregate investment by 25.1% (0.15 percentage point) more by the end of the five years following the policy's introduction. Output-increasing effects of the subsidy policy also show some degree of state-dependence through their effect on wage and capital accumulation. Such a policy, introduced during a boom, would increase output by 7.1% and 7.0% more on impact and cumulated in five years, respectively. Analyzing the impulse response affirms that the effectiveness of investment support policy would significantly depend on whether it is introduced in a boom or a recession, even taking into account general equilibrium forces.

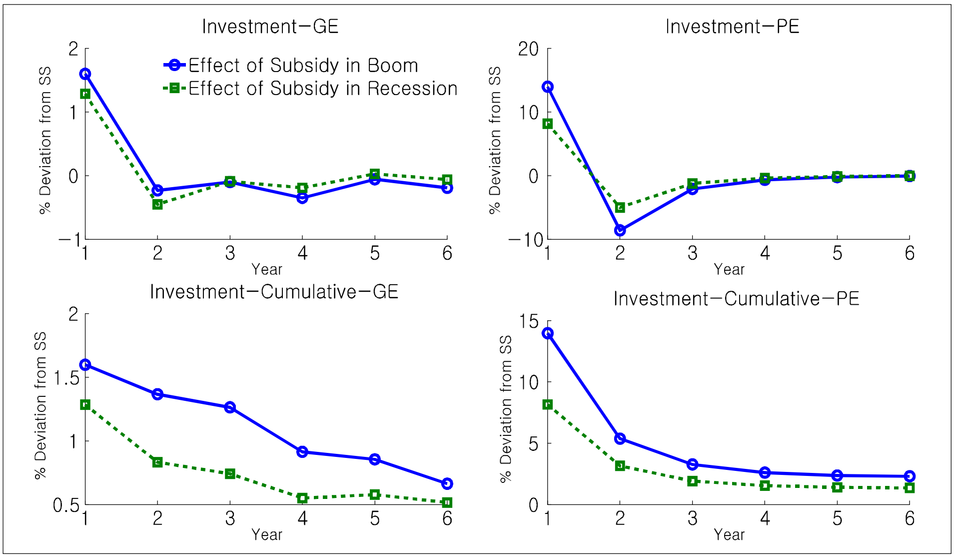
[Figure 12] State-dependent effect of investment subsidy



Note: The solid lines represent dynamic movements of the variable in response to the *positive* aggregate productivity shock and investment subsidies at time 1, while the dashed lines represent movements in the variable in response to the *negative* aggregate productivity shock and investment subsidies at time 1.

One interesting approach is to separate the mitigating effect of variations in aggregate consumption on state dependence of investment subsidy policy. For this purpose, in Figure 13, I compare the degree of state dependence under the general equilibrium environment to that under the partial equilibrium environment. Under the partial equilibrium environment, where there are no variations in consumption and wage, aggregate investment increases more during a boom than in a recession by 52.5% (5.8 percentage points) and 52.0% (1.0 percentage points) on impact and cumulated in five years, respectively. This result shows that the mitigating effect of

[Figure 13] Comparison between general equilibrium and partial equilibrium



Note: The solid lines represent dynamic movements of the variable in response to the *positive* aggregate productivity shock and the investment subsidies at time 1, while the dashed lines represent movements in the variable in response to the *negative* aggregate productivity shock and the investment subsidies at time 1.

general equilibrium forces on the synchronization of investment timing is significant because a measure of state-dependence reduces from 52.5% to 21.8%. However, general equilibrium force does not fully wash out the state-dependent effect of investment subsidy caused by the presence of partial irreversibility and fixed cost of capital adjustment. This result is consistent with the debate between Khan and Thomas (2008) and Bachmann et al. (2013), which shows that whether or not those micro-level investment frictions have aggregate implication depend critically on the quantitative degree of adjustment frictions a plant faces. Bachmann et al. (2013) highlight that, conditional on adjusting capital stock, in their model economy a plant pays 3.6% on average of its annual output as the fixed cost of capital adjustment, whereas corresponding statistics is 0.5% in Khan and Thomas (2008). This difference in the degree of micro frictions leads to different conclusions regarding the aggregate implications of micro frictions. Although the present study follows the calibration strategy of Khan and Thomas (2008) in relying on cross-sectional moments of investment rate distribution, as investment rate distribution in the Korean manufacturing sector is more fat-tailed and skewed than that of the U.S. manufacturing sector, the quantitative degree of adjustment frictions faced by plants addressed in this study is larger than that by Khan and Thomas (2008). In the steady state of our model economy, conditional on adjusting capital stock, on an average per plant pays 1.02% of its annual output as the fixed cost of capital adjustment. In addition, if capital loss associated with partial irreversibility in the disinvestment is considered, conditional on adjusting capital stock, on an average per plant pays 4.2% of its annual output in our model economy. As a result, general equilibrium forces do not fully remove the state-dependent effects of investment subsidy policy, and micro adjustment frictions have non-negligible roles in shaping aggregate investment dynamics.

5.4. Welfare Analysis

While providing investment subsidy during a boom is more effective in terms of investment inducement effect, it might amplify business cycle fluctuations in aggregate variable and reduce the welfare of risk-averse households. To test this possibility quantitatively, I calculate the magnitude of consumption equivalence welfare change across the model economy with the provision of subsidy during booms and recessions.

To implement investment subsidy in an unexpected manner, I calculate the continuation values of plants by using forecasting rules from the stochastic simulation without investment subsidy. For the boom subsidy policy, investment subsidy is provided at the period when aggregate productivity is changed from below or equal to median level to higher than median level, and vice versa for the recession subsidy policy. Moreover, I ensure that the number of periods that investment subsidy is provided for is equalized across boom subsidy policy and recession subsidy policy. With the model economy generating the time series of aggregate consumption and labor, the consumption equivalence welfare change is given in Equation (18) as follows:

$$\sum_{t=1}^{T}\beta^{t}[\log(1+\omega)c_{t,\text{boom}}-\theta n_{t,\text{boom}}] \\ =\sum_{t=1}^{T}\beta^{t}[\log c_{t,\text{recession}}-\theta n_{t,\text{recession}}] \tag{18}$$

Table 7 presents the percent difference of mean and standard deviation of endogenous variables from the simulation of the boom subsidy policy relative to the simulation of the recession subsidy policy. Given that providing subsidy during a boom is more effective in inducing additional investment and consumption, the mean level of consumption and investment is higher along the boom subsidy policy. Simultaneously, because of the income effect associated with increases in mean levels of consumption, the mean levels of labor decrease in the boom subsidy policy. On the other hand, in terms of volatility, by more effectively stimulating inter-temporal substitutions in resources, all three variables exhibit higher standard deviations along the boom subsidy policy simulation. Therefore, boom subsidy policy has a more favorable mean effect, whereas recession subsidy policy has a more favorable volatility effect for the welfare of households in the economy.

[Table 7] Percent difference in aggregate variables across boom subsidy policy and recession subsidy policy

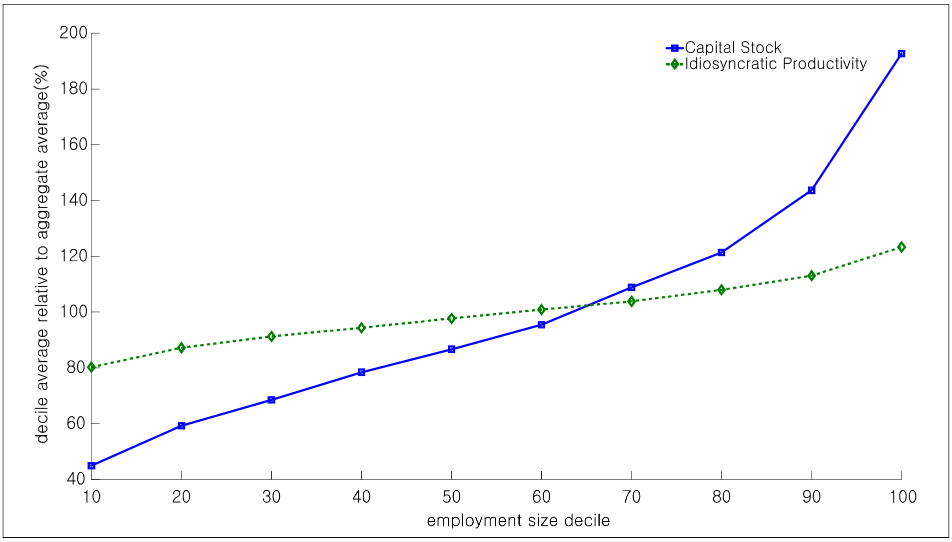
Variable	Consumption	Labor	Investment
mean	0.0009%	−0.0003%	0.004%
S.D.	0.24%	3.00%	1.59%

Eventually, the consumption equivalence (ω) welfare change is calculated as −0.001%. The negative amount of consumption equivalence means that households in the boom subsidy policy enjoy higher levels of utility than do households in the recession subsidy policy. This result shows that mean effect slightly dominates volatility effect. Although providing investment subsidy during booms actually amplifies fluctuations in the main aggregate variables, by more effectively stimulating inter-temporal substitutions in resources, households become slightly better off compared to an economy wherein investment subsidy is provided during recessions.

5.5. Effect of the Size-dependent Investment Subsidy

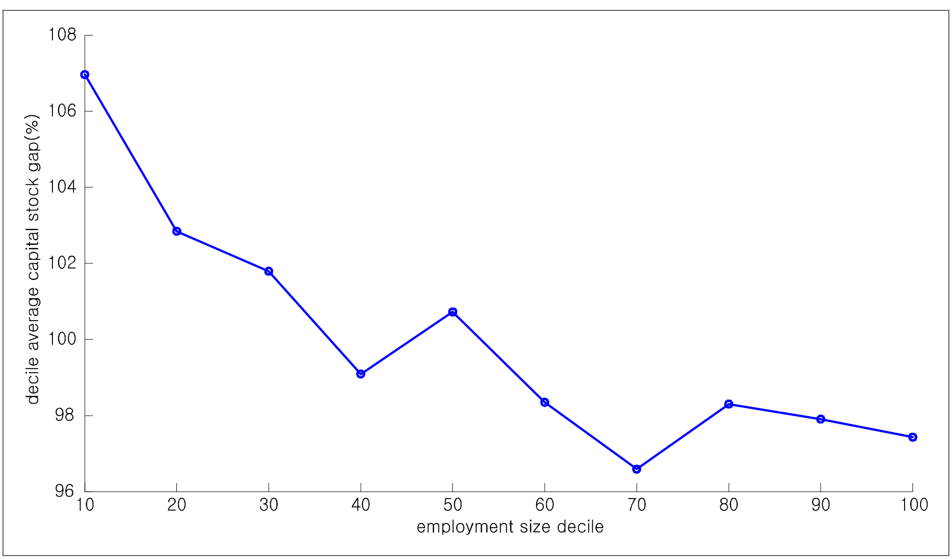
Depending on the present capital stock gaps of the plant, the same amount of investment subsidies can affect the plants' probabilities of investment differently. Therefore, if there is any systematic relationship between capital stock gaps and plants' observable characteristics, then concentrating the investment subsidies can amplify the investment-inducing effect of subsidy. In that regard, I focus on the relationship between employment size of plants, which is the most easily observable plant characteristic, and capital stock gaps. Figure 14 shows the average capital stock of each employment size decile group and their idiosyncratic productivity relative to aggregate means. Both productivity and capital stock increase with employment size decile, but capital stock shows a much steeper deviation from aggregate mean. In other words, lower employment decile plants have relatively higher productivity compared to their capital stock, and vice versa for higher employment decile plants. This happens because of the mean-reverting property of the idiosyncratic productivity process. Plants that have experienced a series of bad realizations of idiosyncratic shocks currently have low levels of capital stock, and their idiosyncratic productivity has a tendency to revert to the mean level. The exact opposite holds true for plants in the high employment decile. Given that capital stock gap is determined by the relative productivity of the plant compared to its current capital stock, capital stock gap has an unconditional negative relationship with the employment size of plants. Figure 15 shows the unconditional negative relationship between capital stock gap and employment sizes of plants. Therefore, plants with small employment sizes may be relatively more responsive to investment subsidies.

[Figure 14] Average capital stock and productivity by employment size decile



Note: The solid lines represent the average capital stock of the employment size decile relative to the aggregate average, and the dashed lines represent the average idiosyncratic productivity of the employment size decile relative to the aggregate average.

[Figure 15] Average capital stock gap by employment size decile



Having found the negative relationship between employment sizes and capital stock gap, I now explore how the effect of the investment support policy would differ if subsidies were to be solely concentrated in smaller plants, solely concentrated in larger plants, or provided equally for plants of all sizes. The three possible scenarios can be summarized as follows:

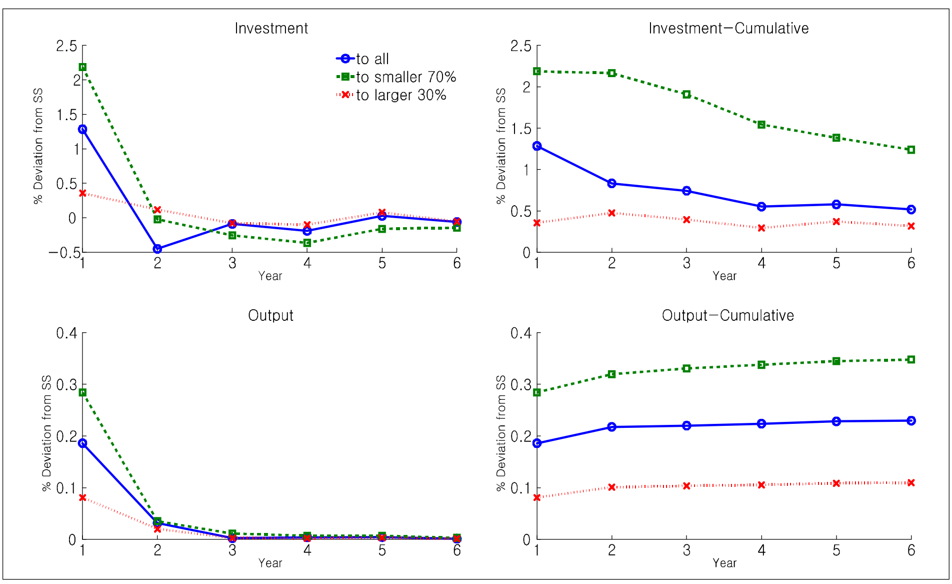
(i) All plants intent on increasing their capital stocks are given subsidies amounting to 0.2% of the investments they are about to make.

(ii) Plants in the lower 70 percentile in terms of employment size make up 49.9% of all investments made throughout the economy under a steady-state equilibrium. These plants intent on increasing their capital stocks are given subsidies amounting to 0.4% ($0.2\times\frac{1}{0.499}$) of the investments they are about to make.

(iii) Plants in the upper 30 percentile in terms of the employment size make up 50.1% of all investments made throughout the economy under a steady-state equilibrium. These plants intent on increasing their capital stocks are given subsidies amounting to 0.4% ($0.2\times\frac{1}{0.501}$) of the investments they are about to make.

Figure 16 shows dynamic movements of variables involved when each of the three policy scenarios takes effect. Policy subsidies are shown to induce the greatest amount of investments overall when they are concentrated in plants in the lower 70 percentile in terms of employment size.

[Figure 16] Aggregated effect of investment subsidy by policy design



Note: The solid lines represent the effect of equally distributed subsidy, the dashed lines represent the effect of subsidy concentrating on the lower 70 percentile, and the dotted lines represent the effect of subsidy concentrating on the upper 30 percentile.

For an investment support policy to have maximal effect, the percentage of subsidies provided under it for investment that would not have occurred without such support should be maximized. Table 8 shows the respective percentages of inframarginal subsidies provided for investments that plants would have undertaken irrespective of policy support and of marginal subsidies provided for investments that plants would not have made without policy support in all three policy scenarios. As observed, the percentage of marginal subsidies is at its greatest when policy support is concentrated in plants in the lower 70 percentile in terms of employment size.

[Table 8] Effect of employment size-dependent subsidy policies on aggregated outcome

	Equal	Small	Large
Total subsidy paid	0.192%	0.195%	0.189%
Inframarginal subsidy	97.7%	96.3%	99.2%
Marginal subsidy	2.3%	3.7%	0.8%
Investment effect on impact	1.28%	2.19%	0.36%
Investment effect up to fifth year	0.52%	1.24%	0.32%
Output effect on impact	0.19%	0.28%	0.08%
Output effect up to fifth year	0.23%	0.35%	0.11%

Note: Total subsidy paid and Investment effect are relative to the steady-state aggregate investment. Inframarginal subsidy and Marginal subsidy are relative to the Total subsidy paid. Output effect is relative to the steady-state aggregate output.

VI. Conclusion

This study shows that given the characteristic patterns observed in the cross-sectional distribution of Korean manufacturing establishments' investment rates, the effectiveness of investment support policy would vary depending on whether the policy is implemented in a boom or a recession.

An analysis of the cross-sectional distribution of investment rates among Korean manufacturing establishments, based on the Mining and Manufacturing Surveys of Statistics Korea, clearly affirms the existing consensus that fixed cost of capital adjustment and partial irreversibility of investment are the main factors determining such distribution.

An analysis of impulse response by using a heterogeneous plant model economy that matches the distribution of investment rates among manufacturing confirms that the short-term effect of an investment support policy on inducing aggregate investment differs depending on whether the policy is implemented during a boom or a recession. The asymmetry of target investment rates among individual plants serves especially to decrease the percentage of plants responding to investment support policy during a recession.

As the key to the success of such a policy lies in the extensive margin response of plants, this study likewise demonstrates the pivotal importance of considering the plants' positions under their own investment cycles before introducing an investment support policy.

Given that our model economy abstracts the entry and exit margin of plant dynamics, one must proceed with caution when interpreting the result of policy design exercises. Relatively smaller plants in terms of employment size in the policy design exercise should be interpreted as small sized but grown enough to avoid significant risks of exiting the market. Hence, plants that belong to the lower 70 percentile in terms of employment size considered may be the lower 70 percentile among plants that have survived in the market for at least 10 years. In that regard, incorporating reasonable plant dynamics observed in the Korean manufacturing sector will be an interesting extension of the current research.

References

Bachmann, Ruediger, Caballero, Ricardo J. and Engel, Eduardo M. (2013), "Aggregate Implications of Lumpy Investment: New Evidence and a DSGE Model," *American Economic Jouranl: Macroeconomics*, 5(4), 29–67.

Caballero, Ricardo J. (1999), "Aggregate Investment," *Handbook of Macroeconomics*, Volume 1, Chapter 12, 813–862.

Caballero, Ricardo J. and Engel, Eduardo M. (1999), "Explaining Investment Dynamics in U.S. Manufacturing: A Gneeralized(S,s) Approach," *Econometrica*, 67(4), 783–826.

Castro, R., G. L. Clementi, and Y. Lee (2015), "Cross-Sectoral Variation in The Volatility of Plant-Level Idiosyncratic Shocks," *Journal of Industrial Economics*, 63(1), 1–29.

Castro, R., G. L. Clementi, and Palazzo, Berardino (2016), "On the Calibration of Competitive Industry Dynamics Models," Mimeo.

Cho, T. (2012), "International Comparison of the Age and Depreciation Rates of Different Types of Assets: Policy Implications," Korea Appraisal Board Real Estate Research Institute, *Real Estate Focus*, (47), 27–36.

Cooper, Russell W. and Haltiwanger, John C. (2006), "On the Nature of Capital Adjustment Costs," *Review of Economic Studies*, 73(3), 611–633.

den Haan, Wouter J. (2010), "Assessing the Accuracy of the Aggregate Law of Motion in Models with Heterogeneous Agents," *Journal of Economic Dynamics and Control*, 34 (1), 79–99.

Dixit, A. (1993), *The Art of Smooth Pasting*, Harwood Academic Publishers: Langhorns, PA.

Foster, L., J. Haltiwanger, and C. Syverson (2008), "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity of Profitability?" *American Economic Review*, 98(1), 394–425.

Han, J. and Woo, J. (2017), "The Effect of SME Support Policy on the Productivity of Korean Manufacturing Sector: Plant Level Growth Profile Analysis," Working paper 17-15, Korea Institute of Public Finance.

House, Christopher L. (2014), "Fixed Costs and Long-Lived Investments," *Journal of Monetary Economics*, 68, 86–100.

Oh, J. (2014), "Efficiency of Production Resource Distribution and Productivity: Comparison of the Korean and Japanese Manufacturing Sectors," Dynamicity of the Korean Economy: Comparison with Japan, Chapter 7, 227–282.

Khan, A. and Thomas, Julia K. (2008), "Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Aggregate Investment Dynamics," *Econometrica*, 76(2), 395–436.

Krusell, P., and A. Smith (1998), "Income and Wealth Heterogeneity in the Macroeconomy," *Journal of Political Economy*, 106, 867–896.

Restuccia, Diego, and Rogerson, Richard (2008), "Policy Distortions and Aggregate Productivity with Heterogeneous Establishments," *Review of Economic Dynamics*, 11, 707–720.

Tauchen, George (1986), "Finite State Markov-Chain Approximations to Univariate and Vector Autoregressions," *Economics Letters*, 20, 177–181.

Veracierto, M. L. (2002), "Plant-level Irreversible Investment and Equilibrium Business Cycles," *American Economic Review*, 92(1), 181–197.

Winberry, T. (2020), "Lumpy Investment, Business Cycles, and Stimulus Policy," Mimeo.

Woo, J. (2017), "Effect of Investment Subsidization Policy for Manufacturing Plants Depending on Business Cycle Phase," *Monthly Public Finance Forum*, 255, 26–56.