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Corporate Investment and Uncertainty: An empirical analysis

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Corporate Investment and Uncertainty
- An empirical analysis

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Abstract

A great deal of the relevant literature mentions that one of the reasons for the 1990s recession in Japan is increasing "uncertainty." To clarify the effect of uncertainty, this study demonstrates the relationship between uncertainty of productivity growth and investment using Japanese firm-level panel data from FY1986-FY2004. It is found that increasing uncertainty of firm-level productivity growth has a negative effect on investment, and especially higher uncertainty in the shifting of a technological frontier has had a larger impact on investment since the mid-1990s. It is also found that such a negative effect is weakened in industries with higher expected growth of demand.

Keywords: investment, uncertainty, technological progress, productivity, panel data

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1 Introduction

Given the country's rapid aging and a low fertility rate, it is necessary to maintain active dynamism for Japan's sustainable growth. Corporate investment is always a key factor. It is extremely important to pin down what factors actually affect firms' investment.

Looking back on Japan's long-term recession in the 1990s and the literature that gives reasons for that recession, it is widely mentioned that increasing "uncertainty" surrounding companies has a negative effect on corporate activities such as production planning, investment, and research and development. However, such "uncertain" influences contain various aspects such as input and output price, consumer demand, technological progress, and economic and industrial policies. Also, it is difficult to quantitatively estimate uncertainty and assess its concrete effect on the economy. Therefore, this study aims to clarify the effect of uncertainty on the economy by focusing on analysis of the relationship between Japanese corporate fixed investment and the uncertainty of productivity growth in FY1986-FY2004, constructing quantitative measures indicating that uncertainty.

Basically, a firm is assumed to decide on investment by comparing the marginal rate of return and cost generated by additional investment, that is, it must predict future return and cost generated by invested capital and is forced to consider uncertainty in the future business environment. In the context of economic theory, a number of studies argue the relationship between uncertainty and investment, but there are contradictory views on such a relationship. Also, some empirical studies explore the relationship by defining various proxies for uncertainty at various levels such as firm, industry, and country.

This paper also mainly investigates empirically the relationship between uncertainty and investment, but builds on the previous empirical studies on the following points. First, this study focuses on uncertainty of productivity growth, which involves technological progress in an economic context, one of crucial factors for economic growth. It is assumed that the level of uncertainty of productivity growth influences a firm's decision for investment because it must consider the level of its own productivity and the highest level of productivity in the industry. Second, by constructing unique variables indicating productivity growth based on Japanese firm panel data, this study elaborated on the effect of uncertainty on investment in estimating investment function. Third, further investigation is made into whether the effect of uncertainty in productivity growth on investment depends on expected demand growth rate at the industry level.

Section 2 then summarizes theoretical literature on the relationship between uncertainty and investment, and section 3 covers previous empirical studies on this relationship. Section 4 and 5 address the empirical framework of this study and specify the estimating models. Section 6 describes the data and how to construct the variables used in this study. Section 7 and 8 demonstrate findings through the sample data and the estimation of the investment function. Section 9 draws conclusions from the results.

2 Theoretical literature on investment under uncertainty

If firms make decisions on fixed investment from a medium- or long-term perspective, they need to consider the uncertainty of the future environment on that investment. In the early-1970s, theoretical literature began to argue about the relation between uncertainty and corporate investment, and Hartman (1972) introduces a discrete-time dynamic model of a risk-neutral firm with adjustment costs to suggest that increasing uncertainty on an output price under perfect competition encourages investment of a firm. Abel (1983) and Abel and Eberly (1994) loose Hartman's assumption of a random price in each period, including the current period, and show that the positive relationship between increasing uncertainty and investment suggested by Hartman (1972) generally holds for competitive firms. Because Abel and Eberly assume a convex adjustment cost function, increasing uncertainty on an output price leads to increasing the marginal product of capital and encourages a firm's investment.

On the contrary, Pindyck (1982) introduces a continuous-time model with the assumption of a stochastic price in the future periods to demonstrate that increasing uncertainty on an output price leads to increasing investment, as suggested by Hartman (1972), only if a marginal adjustment cost function is convex, and that increasing uncertainty suppresses investment by a firm facing a concave marginal adjustment cost function. McDonald and Siegel (1986), Pindyck (1988), and Dixit and Pindyck (1994) apply the real option theory into explaining irreversibility of investment, and show that increasing uncertainty would reduce investment because of its irreversibility. They assume the presence of asymmetric adjustment costs: the cost of settling capital stock is much lower than that of removing it. If it is assumed difficult to reasonably sell or scrap property once a firm has invested in it, a firm may have the choice to postpone launching an investment project until uncertainty in future revenues of the investment is reduced. The value of an option to postpone investment will increase when uncertainty of future revenues increases if the assumption of irreversibility of the investment holds, and a firm decides on investing only when the future returns of the investment exceed a threshold including its real option value of waiting to invest. That is, there is a threshold return for a firm's decision on investment, and the threshold rises as uncertainty increases.

In that context, Caballero (1991) and Caballero and Pindyck (1996) extend the previous literature and explain the effect of uncertainty on irreversible investment in two ways: the first is that under uncertainty a firm's current investment affects the expected marginal profitability of capital, and the second is that competitors' investment affects the marginal profitability. In terms of the second way, they show that, if firms are nearly competitive, the effect of adjustment-cost asymmetries has little to do with the sign of the relation between increasing uncertainty and investment, and even the proposition of Hartman-Abel holds. Dixit and Pindyck (1994) also point out the possibility that the value of waiting to invest reduces the assumption of competitors' entry to market.

3 Empirical literature on investment under uncertainty

Since the 1990s, empirical studies on the relation between uncertainty and investment have followed growing theoretical literature. As stated above, the arguments of the theoretical literature have contradicting results on the relation between uncertainty and investment, and thus empirical studies have sought to show whether such relation is positive or negative. Huizinga (1993), using macroeconomic and industry-level data, empirically analyzes the impact of inflation uncertainty on the allocation of resources through real wages, output, and profits in U.S. manufacturing in 1954-1989. That time-series analysis shows that a short-term increase in uncertainty of real wages and a long-term increase in uncertainty of the real output price lead to lower investment performance, while the result of the cross-sectional analysis indicates that industries with higher uncertainty in input prices have lower investment and those with higher uncertainty in output prices have higher investment. Pindyck and Solimano (1994), using macroeconomic fundamentals of 30 developing and industrialized countries in 1962-1989, shows that a higher volatility of the marginal profitability of capital increases the required return for investment and reduces investment spending in the short run. From a different perspective on measures for uncertainty, Ferderer (1993) uses U.S. macroeconomic data in 1969:3-1989:1 and the risk premium in the term structure of interest rates as a measure for uncertainty, and finds that uncertainty has a negative impact on investment spending by using an empirical investment model based on Tobin's q.

In order to investigate the relation between uncertainty and investment in more detail, some empirical literature use panel data on individual firms. Leahy and Whited (1996) develops a measure of the uncertainty from the variance of the firm's daily stock return for each year. Using panel data on 772 U.S. firms in 1981-1987, it indicates that an increase in uncertainty decreases investment through its indirect effect on marginal q. Driver et al. (1996) and Bulan (2005) also use firm-level data and the volatility of assets returns to quantify if uncertainty has an negative effect on U.S.

manufacturing investment. Particularly, Bulan (2005) focuses on the effect of the variance of a firm's idiosyncratic shocks among the volatility of stock returns. Ghosal and Loungani (1996, 2000), and Guiso and Parigi (1999) look at other measures like variance in future demand for a firm's products, output price and profit as proxies of uncertainty, and demonstrate that higher uncertainty decreases the investment of U.S. and Italian firms, especially in such cases as less-concentrated, highly competitive markets, and small-firm-dominated industries.

Compared with the overseas literature, until recently there had been very few empirical studies on the relation between uncertainty and investment of Japanese firms, especially those that use panel data. Ogawa and Suzuki (2000) analyzes the effect of uncertainty on investment using panel data on Japanese manufacturing firms in 1970-1993 with the uncertainty measure as the standard deviation of a firm's sales growth rate. They find not only that aggregate and industry-wide uncertainty has a more sensitively negative effect on investment, but also that material industries are more sensitive to the negative effect of uncertainty than machinery industries because of less depreciation of the former industries' tangible assets. Using a similar firm-level data set, Suzuki (2001) develops a nonlinear investment model with uncertainty measures such as the standard deviation of the marginal return on invested capital and of its expected value estimated by an autoregressive forecasting model. It finds that higher uncertainty increases the threshold of investment in specific industries and dependent on the size of firms.

Tanaka (2004) focuses on investigating what characteristics of industries and markets have an influence on the negative relationship between uncertainty and investment. By using the growth rate of real sales as a measure of uncertainty and panel data on Japanese 514 manufacturing firms in 1987-2001, his study demonstrates that the negative relationship between uncertainty and investment is significant especially in industries with high concentration, those with less used or leased assets, those with a longer technology lifecycle, and those with further financial constraints.

Nishioka and Ikeda (2006) use panel data on Japanese manufacturing firms with the empirical probit and tobit models, and shows that increasing uncertainty measured by the standard deviation of the real sales growth rate has a significant positive effect on increasing the threshold of q for investment, whereas such an effect is less than the effect of the changes in q because the variance of the threshold of q is smaller than the variance of q itself.

4 Empirical framework

As noted above, while the theoretical literature demonstrates that the sign of the effect of uncertainty on investment depends on the assumptions in terms of the shape of the adjustment cost function, its asymmetric nature and irreversibility, a number of empirical studies have shown the negative relation between higher uncertainty and investment and they consider the reason for that relation is derived from characteristics such as irreversibility, competition, and so forth. Also, most empirical studies use the variance of a firm's sales growth rate as the measure for uncertainty.

Although related to the recent studies of Tanaka (2004) and Nishioka and Ikeda (2006), this paper seeks to empirically test the hypotheses that the negative relationship between uncertainty of productivity growth and investment by using panel data on Japanese firms from FY1986-FY2004, and that the relationship is influenced by industrial characteristics such as expected demand growth in each industry. The relationship is weakened if the future demand is greatly expected, while it is strengthened if the expected growth rate is lower. The latter hypothesis is based on the argument that the option value to postpone investing would be smaller in an industry with largely expected demand growth, because the cost of selling or removing capital stock is relatively small if high profitability is generally expected in the industry.

This investigation involves several important issues on the uncertainty-investment relationship, which the previous empirical literature did not cover. First, this study focuses on the uncertainty in firm-level productivity growth. Most previous studies defined the uncertainty as a variance in the expected demand calculated by a firm's real sales in the previous periods, and demonstrated the uncertainty-investment relationship as influenced by industry characteristics. However, when a firm decides whether to invest in a specific project, in order to expect future demand, it will consider the productivity levels and differences of the firm and other competitors as well as the previous sales themselves. In this study, the productivity growth rates of individual firms are calculated by using Data Envelopment Analysis (DEA), and the variance in those rates is used as the measure for uncertainty.

Second, in order to consider the characteristics of each industry which influence the uncertainty-investment relation firms' expected future demand growth rates are used. Using a corporate survey conducted by the Cabinet Office that collected direct answers about future demand growth rates of industries to which respondents belong, the effect of the difference in expected growth of each industry on the uncertainty-investment relation could be directly investigated.

Third, the sample in this study covers most listed firms from FY1986 to FY2004, which is useful for investigating the long-term and short-term effects of uncertainty up to the current economic recovery cycle.

5 Empirical model specifications

This analysis consists of the following steps: First, I estimate basic Tobin's q-type functions of fixed investment using panel data on listed Japanese firms. Second, I construct measures of uncertainty in firm-level productivity growth and apply them into the q-type investment models to test the significance of the negative effect of uncertainty on investment. Third, the variable that represents the expected demand growth rate of each industry is added into the models to test whether the effect of uncertainty is influenced by differences in expected demand growth.

The basic empirical model used is Tobin's q-type fixed investment function. When the expected present value of returns from a marginal investment of capital to some extent exceeds the cost of the marginal increase of capital, a firm decides to invest in that capital. Thus, according to the method suggested by Suzuki (2001), this study estimates marginal q by each firm. In addition, in order to compare with the results of marginal q function, this study also computes average q, which is the ratio of a firm's market value and replacement cost of the firm's capital, by referring to the method used in Hori et al. (2004). According to Hayashi (1982), average q is equal to marginal q under the assumption of an efficient stock market, a linear homogeneous production function, and a perfect, competitive market. Then, the basic model of investment for panel data estimation is specified as follows:

$$\frac{I_{i,t}}{K_{i,t-1}} = \alpha + \alpha_i + \beta q_{i,t} + \gamma UC_{i,t} + \zeta UC_{i,t} \cdot ED_{j,t} + \varepsilon_{i,t} \qquad (1)$$

$I_{i,t}/K_{i,t-1}$ indicates the level of the investment ratio, which is the current real fixed investment of a firm, *i*, divided by its previous real capital stock, and *q* denotes marginal q or average q. Also, since investment is assumed to have irreversibility, the threshold for decision of investment suggests the option value of waiting to invest, and $UC_{i,t}$ that represents the variable for uncertainty of firm *i*, productivity growth is added to test whether a growing of this has a negative effect to $I_{i,t}/K_{i,t-1}$ through increasing the threshold for investment. In addition, the interaction term of $UC_{i,t}$ is introduced and $ED_{j,t}$ denotes the expected real growth rate of demand in industry *j* that firm *i* belongs to, representing the indirect effect of industry-level expected growth on the relation between the uncertainty and investment. α_i denotes a fixed effect for firm *i*, because a fixed effect model is chosen by Hausman tests against a random effect model for all estimations in this study.

6 Data set and construction

Sample firms

The sample in this study consists of listed Japanese firms from FY1986 to FY2004, the financial data for which are obtained from the Corporate Financial Databank by Development Bank of Japan. This database covers the financial data set of all listed Japanese firms on all stock markets except for financial institutions from

FY1956, but the focus here is on the period from FY1986 to FY2004 and excludes agriculture, forestry and fisheries, and utilities, due to the limited availability of the Databank and other related data for estimating all variables explained in the later sections. As Table 2 shows, the number of sample firms is around 1,500-2,000, which covers most of the listed firms except those stated above. That depends on the availability of the variables for estimating models in the sample period of FY1986-FY2004, and thus the sample is unbalanced panel data.

Real investment and capital stock

This study basically follows the method discussed in Hayashi and Inoue (1991) and calculates real investment and capital stock by each kind of asset: nonresidential buildings, structures, machinery, transportation equipment, and instruments and tools. By each asset, nominal gross investment is calculated as the change in the book value of net capital stock plus accounting depreciation. Real investment is calculated by dividing nominal one by the producer price index relevant to the industry to which a firm belongs.

Capital stock is calculated as follows:

$$K_t = (1-\delta)K_{t-1} + I_t \qquad (2)$$

where K_t denotes real capital stock at the end of year t, I_t denotes real capital investment in year t, and δ denotes the physical depreciation rate. The depreciation rates used are the same as those used in Hayashi and Inoue (1991). The benchmark of K is defined as the real value in the year when a firm was first listed. The real capital stock at the benchmark year is calculated by the book value at the benchmark year deflated by the average capital goods price weighted by each firm's share of capital assets in the year.

Tobin's q

Tobin's q is introduced into the equation of (1) by calculating marginal q and average q. The proxy for marginal q is calculated as follows:

$$MQ = \frac{MRC / CC}{IGP} \tag{3}$$

$$MRC \approx ARC = \frac{NI + DP + IP}{K} \tag{4}$$

$$CC = \frac{IPBP}{IL} \cdot (1 - \tau) + DPR \tag{5}$$

MQ denotes marginal q, *MRC* marginal return on invested capital, *CC* capital cost, *IGP* investment goods price, *ARC* average return on invested capital, *NI* net income after income tax, *DP* amount of depreciation, *IP* interest paid, *IPBP* interest paid including amortization of bond premium, *IL* interest-bearing liabilities, τ effective tax rate, and *DPR* accounting depreciation rate, respectively. This is a similar procedure as the estimation used in Suzuki (2001), and this marginal q assumes that a firm predicts the future marginal return on the currently invested capital under static expectations.

Referring to the discussion in Hori et al. (2004), average q is calculated as follows:

$$AQ = \frac{\frac{(HPS + LPS)}{2} \cdot NS + IL - IA - MA}{K_{rp}} \tag{6}$$

AQ denotes average q, *HPS* highest price of share, *LPS* lowest price of share, *NS* number of shares outstanding, *IA* inventory assets, *MA* miscellaneous assets, K_{rp} replacement value of fixed assets at the end of the previous term, respectively. Ogawa et al. (1996) and Fukuda et al. (1999) estimate tax-adjusted q, which considers the present value of tax savings on the depreciation allowances on previous and current investment. However, the definition in this paper does not consider the tax effect on investment, due to the discussion in Hori et al. (2004) that suggests a high correlation between tax-adjusted q and tax-unadjusted q.

Expected demand

To directly capture future demand growth rates expected by firms, data is used from the Annual Survey of Corporate Behavior released by the Cabinet Office. In this survey, listed companies provide their own forecasts for the next-year, next three-year, and next five-year growth rates of industry-specific demand. Data on the next three-year expected real growth rate is adopted.

Uncertainty of productivity growth

Productivity is defined in this paper as the extent to which output is generated by using production factors efficiently. When production factors are used most efficiently and it would be impossible to produce the same volume of output with fewer production factors, the isoquant curve represents a technological frontier, and the degree of efficiency is calculated by deviation from the technological frontier.

In order to estimate the technological frontier and the deviation of each firm among the sample set from the frontier, DEA is used. This has recently grown in popularity as a non-parametric method of measuring productivity[3]. The method of DEA as estimating efficiency of production is originated from the linear-programming model. Debreu (1951) and Farrell (1957), and Charnes et al. (1978) and Färe et al. (1985) are typical literature on empirical applications of DEA.

As the interest in this study is the variance of growth rates of each firm's productivity, changes in productivity growth need to be dynamically comprehended. For that, according to the DEA method, both a change in the deviation from the frontier and a change in the frontier itself are captured. The basic concept of DEA is summarized as follows: In Figure 1, it is assumed that a firm produces one output, Y (value added), by two inputs, L (labor) and K (capital). The X axis represents an

[3] Since DEA is a non-parametric approach of measuring productivity, it is not based on the assumption of profit maximization of firms, on which the Tobin's q-type investment function depends. Thus, the uncertainty variable, *UC*, constructed here from MPI, is considered to be a proxy for indicating the uncertainty of productivity growth.

inverse of Y/L, labor productivity, and the Y axis represents an inverse of Y/K, capital productivity. The line F_t represents the technological frontier at period t, and the line F_{t+1} represents the frontier at period $t+1$. The shift from F_t to F_{t+1} shows a time-series change in the technological frontier itself. When the frontier shifts, the productivity of the firms deviating from the frontier also changes. In Figure 1, the deviation from the frontier of the firm A at t is A_tB, and at $t+1$ it changes to $A_{t+1}E$ due to the shift of the frontier from F_t to F_{t+1}. Thus, the total time-series growth change in each firm's productivity consists of the change in the frontier itself and that in the deviation from the frontier.

(FIGURE 1 ABOUT HERE)

Technically, Färe et al. (1994) define that a change in the technological frontier itself as a technical change, and a deviation change from the frontier as an efficiency change. In Figure 1, the former change is defined as $(OC/OA_t)/(OE/OA_{t+1})$, and the latter as $(OB/OA_t)/(OD/OA_{t+1})$. Both values are estimated and the combined change of the two named as the Malmquist productivity index (MPI), which determines the geometrical mean of the two as $\sqrt{\frac{OC/OA_t}{OE/OA_{t+1}} \cdot \frac{OB/OA_t}{OD/OA_{t+1}}}$. The Appendix further explains this definition of MPI, according to Färe et al. (1985).

For calculating MPI, I construct firm-level value added, labor input, and capital input using the method of Hayashi and Inoue (1991). Real value added is calculated by deflating nominal corporate profit. Capital input is calculated by multiplying the industry-level utilization rate and firm-level real capital stock, K, explained above. Labor input is calculated by multiplying the firm-level number of employees and industry-level regular and non-regular working hours. See Shinada (2003) for further details of data construction. Since MPI is strongly influenced by the size of sample firms, MPI is individually calculated by the middle division of industrial classification in the DBJ database in order to decrease the influence of differentials in levels and distributions of firms' inputs and outputs by industry.

Then, three proxies are calculated for productivity uncertainty: the variance in three-year MPI, in three-year technical change, and in three-year efficiency change[4]. Three variables for uncertainty are put into equation (1) to statistically test those effects on investment.

7 Descriptive statistics

Table 1 shows the descriptive statistics of the main variables for estimating equation (1). The means of *I/K* are from 0.05 to 0.18 in the sample periods, and this trend is similar to the investment-capital stock ratio in the National Accounts, which means the sample data properly represent the trend of *I/K* as a whole.

(TABLE 1 ABOUT HERE)

AQ and *MQ* have a similar trend with *I/K*, and this implies Tobin's q as a primary factor for investment. However, the standard deviations of *AQ* are much larger than those of *MQ*, because the impact of the volatility of stock prices is typically large especially before and after the bubble years FY1989-FY1990.

malm indicates MPI as one of variables for *UC*. MPI=1 means that no growth is seen in a firm's productivity from *t* to *t+1*, while MPI>1 means positive growth at the rate of MPI-1, and MPI<1 means negative growth. In the 1990s, after the bubble years, the mean of MPI consecutively showed negative growth, but in the 2000s the trend of MPI represents positive growth.

malm_sd stands for the standard deviation of *malm* over three years. While the variance of MPI in the first half of the 1990s is around 0.10-0.13, the variance in the 2000s rises to around 0.2. This implies uncertainty in overall productivity growth has

[4] It should be noted that values of the technical change and the efficiency change range from zero to one by their definition described above, and do not follow the normal distribution. As Simar and Wilson (2007) state, that leads to statistical problems when the efficiency values are regressed on exogenous variables. In this paper, treating standard deviations of those values as independent variables, the normality of standard deviations of the MPI, technical change and efficiency change are checked by way of the Shapiro-Wilk test.

become larger in the 2000s.

malm is divided into *eff* and *tech*: *eff* represents an efficiency change and *tech* represents a technical change. According to Table 1, most of the years *tech* reflects a positive growth (*tech*>1) seem correspondent to the recovery cycle of business in the sample period, while *eff* constantly shows a positive growth. Especially in the 2000s, *tech* tends to be negative growth (*tech*<1), while *eff* continues to be positive growth.

eff_sd represents the standard deviations of efficiency change. The sample mean of *eff_sd* has an upward trend from the second half of the 1990s to the 2000s, which means that the difference in productivity between the firms with highest productivity and the other firms has had a larger variance in that period, and the uncertainty of a firm's relative productivity deviation from the most efficient firm's productivity is getting higher.

tech_sd denotes the standard deviations of technical change, which means variance in shifts of the technological frontier from the previous year to the current year. In terms of uncertainty, the time-series trend of the mean of *tech_sd* after the second half of the 1990s is, on average, similar to that of the mean of *eff_sd*.

Thus, according to the descriptive statistics as above, it is implied that the catch-up of non-efficient firms toward the most efficient firms, not a positive shift of the technological frontier of the most efficient firms, contributed to recovery of productivity growth as indicated by MPI in the 2000s. On the other hand, it is also represented that the uncertainty in both the technological frontier's shift and relative change of productivity deviation from the frontier increase in the same period.

8 Estimation results

Table 2-1 shows the result of panel data estimation with linear regression, according to a basic investment function with one explanatory variable, Tobin's q, on *I/K*. In terms of both marginal q and average q, q has a significant positive effect on *I/K*. However, the coefficients of q are quite small.

(TABLE 2 ABOUT HERE)

Table 2-2 represents the result of the same linear regression but adding the uncertainty variable, *malm_sd* into the equation for 2-1. The sign of the coefficient of *malm_sd*, the standard deviation in MPI over three years, is expected as negative on the hypothesis that increasing uncertainty decreases investment. According to the result of the estimation with average q, however, the size of the coefficients of q turns out to be a fair level compared with the previous literature such as Suzuki (2001) and Hori et al. (2004). The coefficient of *malm_sd* is negative but insignificant. By the estimation with marginal q, the coefficient is positive, and the variables of the uncertainty in those models are not stable.

Table 2-3 shows the result of adding the interaction term of *malm_sd* and the rate of expected growth in the next three years in order to test the significance of the indirect effect of industry-level expected growth on investment. The hypothesis here is that, when a firm has a strong expectation of future demand of the industry to which it belongs, it is willing to invest in capital even if the uncertainty in productivity is increasing. The results of both the average and marginal q models indicate that the coefficient of *malm_sd* turns out to be significantly negative, and the sign of the interaction term is significantly positive. The results support the hypothesis, and demonstrate that the negative effect of uncertainty in productivity is weakened if the industry-level expected demand increases.

Table 2-4 represents the results by decomposing *malm* into *eff* as an efficiency change and *tech* as a technical change and adding their standard deviations to the equation for 2-3.1 in order to investigate what kind of uncertainty in productivity growth primarily influences investment. The results suggest that higher variances in decomposed productivity indices have a significant negative effect on investment, and a higher rate of expected demand growth in an industry weakens such a negative effect. The results are robust in both models, with average and marginal q.

In terms of the sizes of the coefficients of *eff_sd* and *tech_sd*, the latter has a larger negative impact than the former. This means that the negative effect of uncertainty in shifting of a technological frontier is larger than in the relative deviations of firms' productivity from the most efficient firm's productivity, when industry-level expected growth of demand is controlled.

The result of the last estimation implies that, for example, even if a non-efficient firm, which is behind the frontier line, is constantly willing to invest in minimum fixed capital, such as replacing old machines with new ones, for maintaining its own productivity level, it hesitates to increase additional investment for research and development when the highest firms' productivity is volatile and/or the future technological path of the industry is unclear. For another example, it implies that, even under the circumstance that a non-efficient firm easily imitates and uses technology of the most efficient firms, overall investment of a firm is weakened when uncertainty in the trend of the technological frontier increases.

In addition, the result implies that that relationship does not depend on the expected growth rate of industries: the effect of uncertainty in a technological frontier is larger even for a firm producing mature products or belonging to a mature industry with less demand growth.

Tables 2-5 and 2-6 show the coefficients of uncertainty variables, based on the same equation for 2-4 but estimated by dividing the sample period into FY1986-FY1994 and FY1995-FY2004. Looking at the result of the marginal q model estimation, although the significant levels of the coefficients are lower, we can find that the negative effect of *tech_sd* is larger than that of *eff_sd* in FY1995-FY2004, while the result in FY1986-FY1994 is opposite. This suggests that uncertainty in shifting of a technological frontier has had a larger effect on investment, and the expectation of such shifting has recently been more important in firms making decisions on investment.

In terms of interpretation of those results, we should consider the possibility that the index of productivity growth could be influenced by demand in the model. This is because firm-level utility rates of capital and labor inputs cannot be adjusted and the influence of demand on the productivity term cannot be completely removed. Backward productivity growth might derive from negative shock of demand. Thus it should be noted that the indices of uncertainty of productivity growth here could be partly interpreted as uncertainty of demand shock as well as that of pure technological progress.

In order to test the robustness of the results above from the viewpoint of endogenous bias, the dynamic panel data models are estimated using GMM estimators indicated by Arellano and Bond (1991). Table 3 shows the results of estimating the models in Tables 2-3 to 2-6 by using the Arellano-Bond models. Table 3-1 shows that the estimation result of the model including average q holds the significance of all coefficients and the sizes of the coefficients are almost similar to those of the OLS estimators in Table 2-3. This implies robustness of the model, while the coefficient of the standard deviation of productivity growth turns positive in the model including marginal q, which implies possible endogenous bias.

(TABLE 3 ABOUT HERE)

Table 3-2 represents the dynamic panel estimation results of the models equivalent to those of 2-4 to 2-6, which include the variables of average q, *eff*, and *tech*. The signs and significance of the coefficients are almost held in Table 3-2, and those sizes are overall comparable to Table 2. Table 3-2 also represents the results of the estimation with divided sample periods, and the implication that *eff_sd* has a larger effect on investment in FY1986-FY1994 while it has a smaller effect in FY1995-FY2004 is maintained.

Tables 4 and 5 show the results from estimating the same dynamic panel data models in Table 3 by industry: manufacturing and non-manufacturing. The estimation results are almost same as those of the all-industry models in Table 3, but the tendency for *eff_sd* to have a larger effect on investment in FY1986-FY1994 but a smaller effect in FY1995-FY2004 is represented more clearly in manufacturing than in non-manufacturing. This implies that the uncertainty of the technological frontier, especially in manufacturing, has been relatively more important since the late-1990s.

(TABLE 4 & 5 ABOUT HERE)

9 Concluding remarks

This study aims to investigate the factors that weakened Japan's private fixed investment since the 1990s, focusing on the effect of uncertainty in productivity growth on investment. The main hypothesis is that increasing uncertainty in productivity growth, a proxy for technological progress, has a negative effect on fixed investment. In order to empirically clarify such an effect, using the panel data on listed Japanese firms based on their financial statement, I conduct panel data analysis to estimate Tobin's q-type investment functions, introducing the variables of uncertainty in productivity. These variables are computed by the popular DEA method, and overall productivity index (MPI), shifts of a technological frontier (technical changes) and changes in deviation from a technological frontier (efficiency changes) are computed for each firm.

According to the calculated productivity indices above, the following findings are demonstrated: (a) In terms of time-series productivity growth, in the 1990s after the bubble years, MPI consecutively showed a negative growth, but in the 2000s the trend turned to be a positive growth; (b) That overall positive growth in the 2000s is expected to derive from the catch-up of non-efficient firms towards most efficient firms, not a positive shift of the frontier by most efficient firms' technological progress; (c) On the other hand, in terms of uncertainty of productivity growth, both variances in the frontier's shift and the relative deviation change have been increasing in the 2000s.

Moreover, the results from the fixed-effect model estimation of investment functions with average q and marginal q suggest the following: (a) Average q and marginal q are proven significant variables to explain investment by controlling the uncertainty of productivity and the indirect industry-level effect of expected demand growth; (b) Higher uncertainty in productivity growth has a negative effect on investment; (c) Such a negative effect on investment is weakened if a firm belongs to an industry with greatly expected demand growth; (d) Since the late-1990s, higher uncertainty in the shifting of the technological frontier has had a relatively larger negative effect on investment, especially in manufacturing.

A great deal of the relevant literature investigates the factors that weakened private fixed investment in Japan’s lost decade after the bubble collapse, and, from the empirical results of this study, it is demonstrated that increasing uncertainty in firms’ productivity growth is one of those factors, and particularly the uncertainty in the shifting of a technological frontier has recently had a significant effect on investment. Accordingly, a policy implication is suggested in which the government take measures to promote private fixed investment not only by uniform support throughout companies, such as changing depreciation rules in tax reform, but also by encouraging market competition by highly productive firms. For example, deregulation of market entry, support for research and development, and so forth could result in leading firms gaining confidence in the future path of a technological frontier.

However, at the same time, it is expected that firms would enhance their capability of managing risk in various projects and business environment such as investment, research and development, financing, and external demand. Particularly, the risk management of the future technological progress is more difficult for firms on the technological frontier. Thus, for those firms it is important to establish proper risk evaluation and a management system that leads to reducing the negative effect of increasing uncertainty on investment and to efficiently investing in future projects.

Appendix

It is assumed that a firm uses multiple inputs of x_t = (x^1_t, …, x^n_t) to produce multiple outputs of y_t = (y^1_t, …, y^m_t) in the time period $t = 1, \ldots, T$. Production technology is defined using the output set, P, as follows:

$$P_t(x_t) = \{ y_t : x_t \, can\ produce\, y_t \ at\ time\ t \}, \quad t = 1,\ldots,T \tag{4}$$

Production technology is characterized by the output distance function (Färe et al. [1985]) as:

$$D_t^0(x_t, y_t) = \min_\theta \{ \theta : (x_t, y_t/\theta) \in P_t \} \tag{5}$$

The distance function is less than or equal to one, if output y belongs to the production possibility set of x. Particularly, the distance function is equal to one, if y belongs to the technological frontier of the production possibility set, and a firm that produces y is considered most technically efficient.

Using this concept, Färe et al. (1985) shows that the Malmquist productivity index (M) between t and $t+1$ can be calculated by two components as follows:

$$M_{t,t+1}(x_t, x_{t+1}, y_t, y_{t+1}) = \underbrace{\frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)}}_{eff} \cdot \underbrace{\sqrt{\frac{D_t(x_t, y_t)}{D_{t+1}(x_t, y_t)} \cdot \frac{D_t(x_{t+1}, y_{t+1})}{D_{t+1}(x_{t+1}, y_{t+1})}}}_{tech} \tag{6}$$

M of more than one indicates positive productivity growth, while M of less than one negative growth. In the above equation, the term *tech* represents a movement of technological frontier from t to $t+1$, which means improving or worsening of best-practice firms' productivity. The term *eff* represents moving closer (catch-up) to or diverging from the frontier in the period t to $t+1$. M results from combining those two productivity changes.

FEAR 1.0 developed by Wilson (2007) is used for calculating the distance functions and the index. This can handle Data Envelopment Analysis, a popular non-parametric method.

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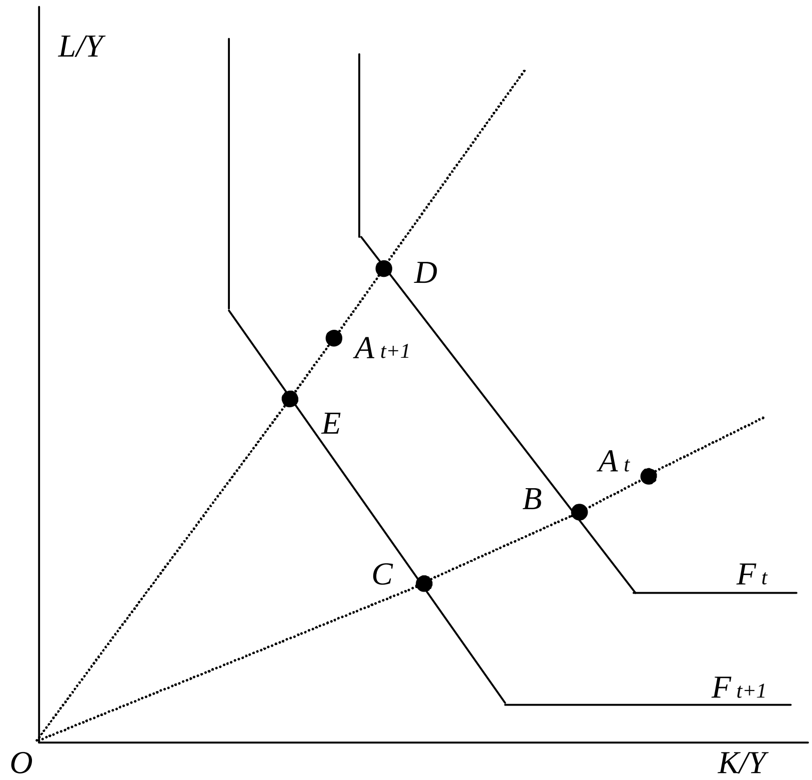

Figure 1. Technical change and efficiency change

	I/K		*MQ*		*AQ*	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
FY1986	0.12	0.12	1.28	0.85	1.97	2.42
1987	0.12	0.12	1.46	1.06	2.59	3.29
1988	0.14	0.13	1.65	1.18	3.24	3.42
1989	0.16	0.15	1.93	1.73	4.13	4.46
1990	0.18	0.15	2.02	2.11	3.55	5.33
1991	0.17	0.15	1.93	2.58	2.27	4.44
1992	0.14	0.14	1.45	1.77	0.91	2.80
1993	0.10	0.13	1.25	1.34	1.34	2.62
1994	0.09	0.11	1.24	1.47	1.44	2.88
1995	0.09	0.11	1.35	1.39	1.09	3.27
1996	0.11	0.12	1.40	1.53	1.33	3.36
1997	0.11	0.12	1.21	2.12	0.30	3.12
1998	0.10	0.13	1.03	1.65	0.05	3.18
1999	0.07	0.11	1.12	1.82	0.98	6.13
2000	0.09	0.13	1.14	2.70	0.83	7.50
2001	0.07	0.12	0.97	2.72	0.50	6.38
2002	0.06	0.12	1.18	3.10	0.12	6.07
2003	0.06	0.12	1.57	4.27	0.36	5.94
2004	0.06	0.13	1.81	4.07	1.13	6.93

	malm	*malm_sd*	*eff*	*eff_sd*	*tech*	*indtech_sd*
	Mean	Mean	Mean	Mean	Mean	Mean
FY1986	1.00	0.14	1.06	0.19	0.96	0.12
1987	1.01	0.17	1.11	0.23	0.93	0.10
1988	0.97	0.12	1.09	0.20	0.92	0.11
1989	1.01	0.11	1.44	0.62	0.89	0.16
1990	0.98	0.10	0.95	0.20	1.56	0.93
1991	1.00	0.10	1.13	0.24	0.95	0.15
1992	1.03	0.14	1.18	0.36	0.99	0.22
1993	1.03	0.13	1.11	0.25	1.00	0.21
1994	1.00	0.12	0.98	0.20	1.08	0.18
1995	0.99	0.11	1.05	0.17	0.97	0.11
1996	0.98	0.12	1.01	0.21	1.01	0.13
1997	1.10	0.20	1.00	0.23	1.17	0.24
1998	1.04	0.14	1.21	0.30	0.90	0.14
1999	0.97	0.15	1.21	0.39	0.88	0.14
2000	1.02	0.19	1.09	0.27	1.03	0.24
2001	1.05	0.20	1.28	0.45	0.93	0.19
2002	1.05	0.25	1.01	0.31	1.16	0.40
2003	1.03	0.21	1.19	0.37	0.92	0.17
2004	1.06	0.20	1.26	0.40	0.89	0.13

Table 1. Descriptive statistics of main variables

All industries

	cons	*AQ*	*MQ*	*malm_sd*	*malm_sd *ED*	*eff_sd*	*eff_sd *ED*	*tech_sd*	*tech_sd *ED*	*R-sq*	*No. of firms*	*Est. period*
2-1.	0.1013***	0.0002***								0.0019	2590	1986-2004
	(0.0006)	(0.0000)										
	0.0947***		0.1118***							0.0519	2586	1986-2004
	(0.0008)		(0.0003)									
2-2.	0.1027***	0.0031***		-0.0016						0.0127	1526	1986-2004
	(0.0009)	(0.0003)		(0.0016)								
	0.0814***		0.0190***	0.0035**						0.0682	1605	1986-2004
	(0.0011)		(0.0005)	(0.0015)								
2-3.	0.1011***	0.0029***		-0.0089***	0.0091***					0.0157	1509	1986-2004
	(0.0010)	(0.0003)		(0.0018)	(0.0011)							
	0.0800***		0.0187***	-0.0033*	0.0088***					0.0716	1588	1986-2004
	(0.0011)		(0.0005)	(0.0017)	(0.0011)							
2-4.	0.1024***	0.0026***				-0.0151***	0.0096***	-0.0171***	0.0053***	0.0215	1509	1986-2004
	(0.0011)	(0.0003)				(0.0020)	(0.0008)	(0.0032)	(0.0008)			
	0.0811***		0.0182***			-0.0077***	0.0077***	-0.0146***	0.0047***	0.0762	1588	1986-2004
	(0.0012)		(0.0005)			(0.0018)	(0.0008)	(0.0031)	(0.0007)			
2-5.	0.1224***	0.0037***				-0.0298***	0.0100***	-0.0092*	0.0028**	0.0060	1072	1986-1994
	(0.0021)	(0.0007)				(0.0078)	(0.0020)	(0.0051)	(0.0012)			
	0.0883***	-0.0009**				-0.0051**	0.0060***	-0.0125***	0.0064***	0.0001	1436	1995-2004
	(0.0013)	(0.0004)				(0.0022)	(0.0013)	(0.0041)	(0.0018)			
2-6.	0.0680***		0.0435***			-0.0135*	0.0052***	-0.0069	0.0018*	0.1038	1132	1986-1994
	(0.0024)		(0.0013)			(0.0074)	(0.0019)	(0.0048)	(0.0011)			
	0.0741***		0.0100***			-0.0025	0.0059***	-0.0084**	0.0065***	0.0578	1509	1995-2004
	(0.0015)		(0.0006)			(0.0019)	(0.0012)	(0.0040)	(0.0018)			

Note: *** denotes significant at 1% level, ** at 5% level, * at 10% level, respectively

Table 2. Estimation results (1)

All industries

	cons	*AQ*	*MQ*	*malm_sd*	*malm_sd *ED*	*eff_sd*	*eff_sd *ED*	*tech_sd*	*tech_sd *ED*	*No. of firms*	*Est. period*
3-1	0.0739***	0.0050***		-0.0030*	0.0103***					1449	1986-2004
	(0.0009)	(0.0002)		(0.0018)	(0.0015)						
	0.0402***		0.0288***	0.0040**	0.0095***					1524	1986-2004
	(0.0012)		(0.0004)	(0.0020)	(0.0015)						
3-2	0.0760***	0.0045***				-0.0136***	0.0097***	-0.0145***	0.0058***	1449	1986-2004
	(0.0024)	(0.0006)				(0.0033)	(0.0013)	(0.0049)	(0.0012)		
	0.0984***	0.0095***				-0.0358***	0.0132***	-0.0146*	0.0048***	1034	1986-1994
	(0.0044)	(0.0012)				(0.0121)	(0.0031)	(0.0077)	(0.0018)		
	0.0778***	-0.0001				-0.0047***	0.0049***	-0.0089***	0.0074***	1391	1995-2004
	(0.0022)	(0.0006)				(0.0031)	(0.0018)	(0.0054)	(0.0025)		

Note: *** denotes significant at 1% level, ** at 5% level, * at 10% level, respectively

Table 3. Estimation results (2)

Manufacturing

	cons	*AQ*	*MQ*	*malm_sd*	*malm_sd *ED*	*eff_sd*	*eff_sd *ED*	*tech_sd*	*tech_sd *ED*	*No. of firms*	*Est. period*
4-1	0.0738***	0.0054***		-0.0047***	0.0061***					955	1986-2004
	(0.0007)	(0.0001)		(0.0013)	(0.0011)						
4-2	0.0761***	0.0049***				-0.0126***	0.0077***	-0.0166***	0.0062***	955	1986-2004
	(0.0007)	(0.0001)				(0.0004)	(0.0003)	(0.0004)	(0.0003)		
	0.0913***	0.0097***				-0.0504***	0.0165***	-0.0144***	0.0055***	777	1986-1994
	(0.0031)	(0.0012)				(0.0080)	(0.0024)	(0.0067)	(0.0014)		
	0.0767***	-0.0019***				-0.0054***	0.0039***	-0.0103***	0.0092***	914	1995-2004
	(0.0010)	(0.0001)				(0.0006)	(0.0004)	(0.0005)	(0.0005)		

Note: *** denotes significant at 1% level, ** at 5% level, * at 10% level, respectively

Table 4. Estimation results (3)

Non-manufacturing

	cons	*AQ*	*MQ*	*malm_sd*	*malm_sd *ED*	*eff_sd*	*eff_sd *ED*	*tech_sd*	*tech_sd *ED*	*No. of firms*	*Est. period*
5-1	0.0860***	0.0042***		-0.0048***	0.0400***					494	1986-2004
	(0.0014)	(0.0001)		(0.0012)	(0.0006)						
5-2	0.0912***	0.0040***				-0.0181***	0.0171***	-0.0095***	0.0047***	494	1986-2004
	(0.0013)	(0.0001)				(0.0003)	(0.0002)	(0.0002)	(0.0001)		
	0.1209***	0.0051***				-0.0236***	0.0145***	-0.0107***	0.0033***	257	1986-1994
	(0.0025)	(0.0002)				(0.0039)	(0.0012)	(0.0016)	(0.0005)		
	0.0900***	0.0013***				-0.0066***	0.0142***	-0.0030***	0.0069***	477	1995-2004
	(0.0019)	(0.0001)				(0.0005)	(0.0003)	(0.0006)	(0.0002)		

Note: *** denotes significant at 1% level, ** at 5% level, * at 10% level, respectively

Table 5. Estimation results (4)