MEASURING RESEARCH BENEFITS WITH IMPORT BAN RESTRICTIONS, QUALITY CHANGES, NON-MARKET INFLUENCES ON ADOPTION AND FOOD SECURITY INCENTIVES

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I. Introduction

Hundreds of studies have been conducted since Griliches (1958) suggested a method for measuring the benefits to agricultural research. Alston *et al.* (2000) reviewed 292 studies that reported 1,886 observations of returns to agricultural R&D. While some studies consider complicated cases, most studies have focused solely on R&D policy. However, it is common that agricultural R&D policy is combined with other policies, such as a price support, subsidy policy, non-market inducement, and import restrictions. Naturally, when the benefits of agricultural research are measured without taking the related policies into account, biased estimates are likely.

The South Korean rice industry provides a good example where several factors affected the adoption of new technology, causing the complications in the measurement of the research benefits. The agricultural R&D policy in Korea for rice was combined with factors such as an import ban, a price support and government purchase program, yield-quality trade-offs, and arguments that there are external benefits, like a public good, associated with self-sufficiency. It is therefore important to evaluate the benefits of agricultural research appropriately and carefully given these conditions.

The revolution in rice production in Asia was triggered in 1966 with the development of IR8 by the International Rice Research Institute (IRRI). Based on IR8, Korea introduced the first high-yielding variety developed through agricultural research in 1972. The argument that prevailed in the 1970s (and continues to the present day) is that self-sufficiency in rice was a public good in Korea. This attitude affected the adoption of the new high-yielding varieties. The Korean government strongly encouraged farmers to adopt the new varieties through a government purchase policy as well as non-

market government inducements. The government purchase policy that had been in place since the 1950s was expanded in the 1970s. Most of the new variety of rice produced was purchased and used by the government or released back on the market at discounted prices. Local officials and extension workers were provided incentives to achieve high local adoption rates. An import ban was also imposed to maintain high domestic prices.

The economic evaluation of high-yielding rice involves innovations to deal with several elements:

- The basic economics of agricultural research and development (productivity-enhancing technology): measuring agricultural research benefits without considering complicating factors. A new method to measure a supply shift caused by agricultural R&D will be presented.

- The price support and government purchase program for a fixed amount of rice from each farm: considering that the remaining amounts were sold in the market, this policy acts like a decoupled income transfer that does not affect the payoff of agricultural research. However, with an introduction of price uncertainty, government purchase policy has a positive effect on production.

- The yield-quality tradeoffs of the technology: this tradeoff should be evaluated as a loss because the gross benefits of research would increase if there had not been a quality change.

- Non-market incentives for the adoption of the new variety rice: the effect of non-market adoption is similar to that of regulation in that it generally prevents profit-maximizers from making adjustments.

- The trade policy that affected returns to higher yields: world price is considered as an opportunity cost. The research benefit in an open economy will be smaller than the benefit in a closed economy.

- The public good argument related to "food security" and self-sufficiency.

Conceptual studies and a few examples from other countries have dealt with some of these issues, but no study has fully evaluated the issues in a real and important setting. For example, Lokollo (2002) explored the effects of modern technology on its adoption and productivity in Indonesia. The Indonesian case is very similar to the Korean case, in that the green revolution was driven by the government. The Philippines has also implemented a government purchase policy like Korea (Martinez, Shively and Masters, 1998). However, there have been few studies that seek to analyze the effect of the purchase policy in terms of agricultural R&D. This paper measures the net research benefits derived from the development of the new high-yielding varieties performed in Korea given this complex setting. During the measurement of research payoffs, several innovations will be presented.

II. Brief History of the Korean R&D on High-Yielding Varieties

The Korean modern varieties were developed in 1968 as a derivative of IR8. IR8 was the first variety of high-yielding tropical rice developed and released by the International Rice Research Institute (IRRI) in 1966. As soon as the potential of IR8 was recognized, it was widely distributed throughout rice-growing countries. Korea also received small sets of breeding materials from IRRI (Chandler, 1992). Research for new varieties that were suitable for the Korean environment had been conducted by the Rural Development

Administration (RDA). In 1968, IR667, a high-yielding hybrid of japonica and indica rice, later called *Tong-il* (literally meaning "unification")*,* was developed. One problem of *Tong-il* rice was that its quality was inferior in taste to conventional rice, in spite of its high-yielding features. Some researchers opposed the spread of new varieties because of its low quality. However, the government decided to provide *Tong-il* seeds for farmers at the end of 1968, despite the opposition by some researchers.

Like other developing countries, the adoption process of *Tong-il* rice was driven by the government. The first problem that the Korean government had to solve was the insufficient supply of seeds. Though the yields of *Tong-il* rice were 30 percent higher than those of conventional varieties, the total quantity of *Tong-il* rice harvested at experimental stations in 1969 was only 12 kg. To shorten the breeding cycles and accelerate the release of *Tong-il* varieties, the RDA decided to grow *Tong-il* rice at the IRRI during the winter season (IRRI; Kim). 4 kg of *Tong-il* seeds sent to the IRRI in October, 1969, were returned as 600 kg in the spring of 1970, and 10 kg in the fall of 1970 were returned as 4.3 M/T in the spring of 1971. In 1972, the RDA got 17,000 M/T from the IRRI.

Besides the insufficient supply of seeds, the RDA was short-handed with the necessary technical consultants to help farmers who adopted *Tong-il* rice. To settle the problem, the RDA employed 1,870 new extension workers in the spring of 1972. Given that the total number of RDA extension workers in 1971 was 2,877, this increase was substantial. These new extension workers were employed solely for the adoption of *Tong-il* rice. Their primary tasks were to visit and consult with farmers, to persuade

growers who did not favor *Tong-il* rice, to monitor the growing situation of *Tong-il* rice, and to report any diseases and insects observed in *Tong-il* fields to RDA headquarters.

With sufficient seeds and extension workers, and some promising results of field tests, *Tong-il* began to be adopted on Korean farms in 1972 (Kim, 1978). To enhance the adoption rates, a target level of adoption was assigned to each extension worker in the provinces. During the adoption process, some extension workers physically removed other varieties from the field that had already been planted in some extreme cases, in order to raise the adoption rate assigned to them. The speed of adoption rate for *Tong-il* rice was so fast that the total area producing *Tong-il* expanded from 9.2% of the total rice cultivated areas in 1972 to 75.5% in 1978 (MAF).

The Korean government took advantage of a purchase policy for rice as well. Though the government purchase program had been implemented since the 1950s, the program changed fundamentally in the 1970s when *Tong-il* rice was introduced. With the introduction of *Tong-il* rice, the government raised the supported prices and expanded the quantities bought by the government. Under this program, real rice prices rose 5.7 percent annually between 1969 and 1979. Compared to the annual growth rate of 2.4 percent between 1980 and 1990, and −1.1 percent between 1991 and 2000, the rate in the 1970s was high. The quantities purchased by the government expanded from 0.35 million M/T in 1970 to 1.4 million M/T in 1978. These quantities accounted for 8.9 percent and 23.4 percent of total rice production. Despite low quality, the Korean government set the same price for *Tong-il* rice as conventional rice so that farmers who adopted *Tong-il* rice could sell more rice at the same price as conventional varieties.

The development and dissemination of *Tong-il,* combined with other policies, led to self-sufficiency in rice by 1976. However, the favorable situation for *Tong-il* was reversed by two events that occurred between 1978 and 1980. One was the outbreak of rice blast disease and the other was the turnover of political power. Although some *Tong-il* varieties were developed to be resistant to diseases, its tolerance to rice blast disease was not good. After an initial outbreak in 1978, blast disease combined with cold weather considerably reduced the 1980 harvest. Between 1979 and 1980, production fell by 36 percent, from 5,545 thousand tons to 3,529 thousand tons.

The political turnover had more important implications for the production of *Tong-il*. With this event as a turning point, *Tong-il* was on the decline. The high price policy was moderated and *Tong-il* was no longer strongly recommended. The growth rate of the government purchase price dropped substantially: it increased by only 0.1 percent in 1982 and decreased by 3.4 percent in 1983. The slow growth in prices continued until the consent of the National Assembly was restored in 1987. Even after the revival, the growth rate of the rice price was not as high as that experienced in the 1970s. Then, in 1989 *Tong-il* began to be purchased separately from other varieties at a lower price. The government finally stopped purchasing *Tong-il* in 1992. After 1992, *Tong-il* rice was no longer planted at farms' level.

III. Measuring Research Benefits

The returns to the R&D on the high-yielding varieties are here measured in terms of welfare changes: a sum of consumer surplus and producer surplus. Though some argue that the economic surplus is not a correct measure of welfare change, it is generally

accepted that the surplus is one of the most plausible measures when the information is highly restricting[1]. The importance of functional forms and features of supply shifts has been controversial for a long time as well. However, a persuasive conclusion was drawn by Rose in 1980. He insisted that the parallel shift of supply is the only realistic strategy that can be chosen when there is little information on the shape of the supply curve or the position at which the single estimate applies (Rose, 1980, p.837). Alston *et al.* (1995) argued, further, that if there is an assumption that the supply shifts induced by research is parallel, then, "the functional forms of supply and demand are unimportant and it is convenient to use a local linear approximation…" (p.64). Hence, we can assume that supply and demand functions are linear, and that the research-induced supply shift is parallel.

In this paper, the first measurement will be done without considering complicating factors. Thus, the results are likely to be overestimated. After being measured in the simplest setting, research payoffs will be re-measured, considering the complicating factors one by one.

3.1. Measuring Research Benefits in the Simplest Setting

As a baseline, we measure the returns to the research on the high-yielding varieties (*Tong-il* rice) without considering complicating factors. It is assumed that the supply-and-demand functions are linear and that the research-induced shift is parallel. In Figure 1, a parallel shift of linear supply is demonstrated. D^T and S^T are the demand and supply curves observed in the market with *Tong-il* in place. If *Tong-il* had not been developed,

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[1]For a more detailed discussion on this issue, see Alston *et al*., pp. 44-48, 1995.

the supply curve would have shifted up by w (w_1 and w_2) to S^{NT} because *Tong-il* was a yield-increasing or a cost-saving technology. As seen in Figure 1, it is assumed that there exists a point along the supply curve where the slope of the supply curve changes substantially (e.g. point j in Figure 1). This assumption is necessary, in order not to allow a supply curve to have a negative intercept in the linear supply curve. A negative intercept of the supply curve implies that some quantities are produced at negative prices.

Figure 1. Aggregated Supply and Demand for Rice in Korea with Shifts Induced by Introduction of *Tong-il*, without Considering a Quality Change
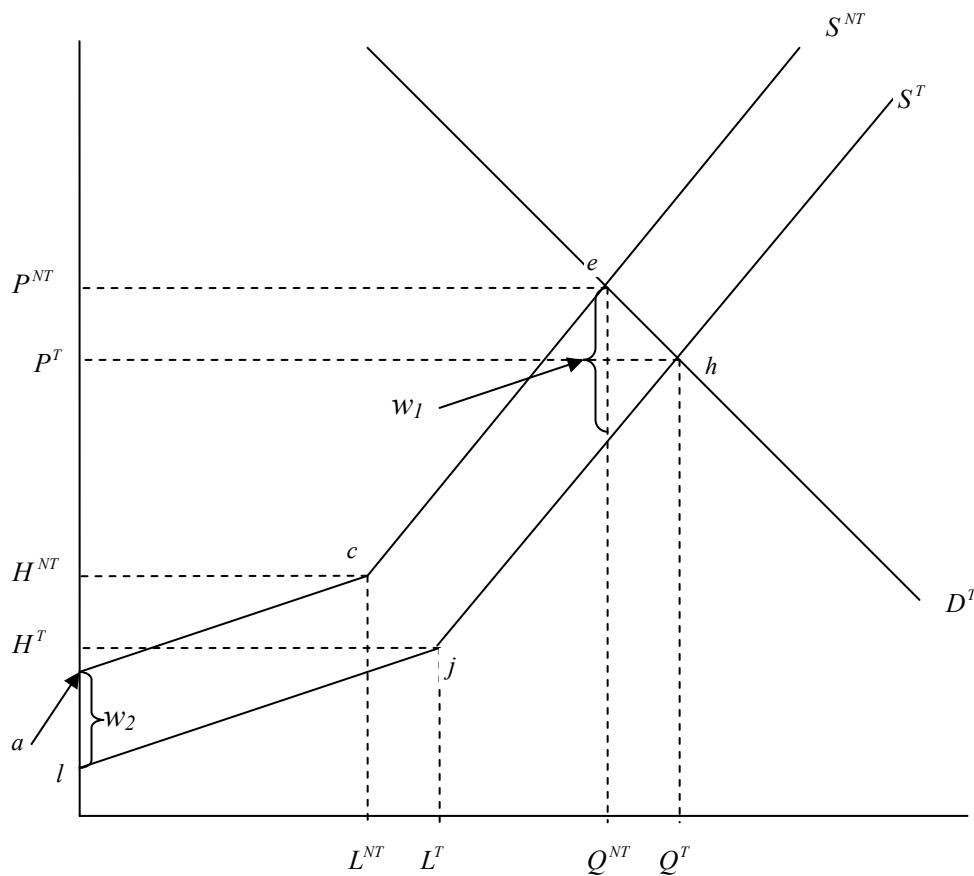
Further, if the possibility of the negative intercepts is not eliminated, the estimates from the supply curves with negative intercepts are likely to be slightly overstated, unless the supply is infinitely elastic. In Figure 1, H^T and L^T designate the price and quantity levels at the kink when *Tong-il* is in place. The price and quantity levels at the kink when *Tong-il* is not in place are illustrated by H^{NT} and L^{NT}. Since those price and quantity levels, in fact, are not the actual price and quantity observable at market, they are represented by H for price and L for quantity, rather than P and Q^2.

Data for Measuring Gross Research Benefits

There are two kinds of price data: the farm-gate prices of *Tong-il* and conventional rice, and the government purchase prices. The source of the farm-gate prices is the National Agricultural Cooperative Federation (NACF), which surveyed and released farm-gate prices. The government purchase prices are the prices set annually by the government for a certain amount of rice. The prices of *Tong-il* rice during the 1972-75 period were missing, because most of the *Tong-il* rice produced during that period was purchased by the government for seeds for the next year. Those prices were calculated by multiplying the farm-gate prices of conventional rice by 0.829 (average ratio of *Tong-il* prices over conventional prices). All prices were deflated by the CPI (2000=100).

The yield data used for the calculation of the benefits of *Tong-il* research were the national average yields of the rice industry. All yields were based on milled rice. On the basis of representative values found in the literature, -0.3 for demand elasticity, and 0.5 for supply elasticity were chosen for the calculation of the research benefits.

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[2] From now on, the superscript T and NT imply the situation with *Tong-il* in place and not in place, respectively. The subscript T and C indicate *Tong-il* and conventional rice.

Expenditures on Research and Extension of *Tong-il*

The Korean government, through the Rural Development Administration (RDA), primarily drove the development, release, and adoption of *Tong-il* rice. Few private research institutes existed in the 1960s and 1970s. Because research done on *Tong-il* by private firms was negligible, expenditure data from the RDA were used as the research cost data. The RDA had many intramural research institutes, but only five of these institutes were related to rice research: the Rice Research Institute, the National Crop Experiment Station, the Institute of Agricultural Science, the Agricultural Mechanization Institute, and the Agricultural Chemicals Research Institute[3]. The data set for these institutes' expenditures on rice research was established by Suh (1992) and was used for this research[4].

Research on high-yielding rice varieties began in 1965 (Kim, pp. 24-25). However, it was difficult to separate the expenditures on *Tong-il* research from the research expenditures on other rice varieties. It was assumed that 25 percent of the 1965 research expenditures on rice were assigned to the development of *Tong-il*. Furthermore, it was assumed that this percentage had grown by 2.5 percent each year until 1979, when it reached its peak at 60 percent. After 1979, it fell by 5 percent until 1990 when the percentage was kept at 1 percent in 1991 and 1992.

Expenditures for extension were allocated by local governments as well as by the RDA. For both sets of extension expenditures, Choi *et al.*'s (2004) data were used. In addition, it was assumed that 80 percent of total extension expenditures were spent on

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[3] For the history and complete list of the RDA's intramural institutes, see Choi *et al.*, 2004.
[4] For the description of this data set, see Suh (1992), p. 65.

Tong-il[5]. This trend continued through 1979. After 1979, the expenditures on *Tong-il*

decreased by 10 percent until 1986. The expenditures decreased by 5 percent in 1987, and

have remained at 1 percent of total expenditures on rice since 1988. All expenditures

were deflated by the CPI (2000 = 100).

Measuring the Research-Induced Supply Shift

One of the important issues related to estimation of research payoffs is to measure the

supply shifts induced by research. When the innovation is related to the improvement in

yield of a crop, there is a simple way to measure the supply shift.

Let y_C and y_T be the yields of conventional and *Tong-il* rice, and A_C and A_T be

the area of conventional and *Tong-il* rice ($\overline{A} = A_C + A_T$). Expressing the quantities in terms

of yield and area,

(1)
$$\begin{cases} Q^{NT} = y_C \times \overline{A} \\ Q^T = y_T \times A_T + y_C \times (\overline{A} - A_T) \\ Q_C^T = y_C \times (\overline{A} - A_T) \\ Q_T^T = y_T \times A_T \end{cases},$$

where Q^{NT} and Q^T indicate the total quantities before and after the introduction of new

high-yielding varieties. Q_C^T and Q_T^T represent the quantities of conventional and new

varieties with high-yielding varieties in place. Then, a *J* percent horizontal shift is

measured as,

(2)
$$J = \frac{Q^T - Q_C^T}{Q^T} = \frac{Q^T - Q_C^T}{Q^*} \times \frac{Q^*}{Q^T} = \frac{y_T A_T}{y_T \overline{A}} \times \frac{y_T \overline{A}}{y_T A_T + y_C (\overline{A} - A_T)},$$

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[5] This assumption does not look unreasonable, considering the situation of the 1970s. In the 1970s, the extension service (including local governments) focused entirely on the adoption and cultivation of *Tong-il*.

where Q^* is the quantity when the new varieties are adopted 100 percent. Some calculations lead to the following:

$$(3) \qquad J = \frac{Q^T - Q_C^T}{Q^T} = \frac{h}{1 - \delta + \delta h},$$

where $\delta (\equiv (y_T - y_C)/y_T)$ and $h (\equiv A_T / \overline{A})$ indicate yield gains over old varieties and adoption rate of high-yielding varieties, respectively[6].

One important implication of (3) is how much a supply curve shifts out depends on just two parameters: adoption rate and relative yield difference. If we know the information on adoption rates of new varieties and relative yield differences between new and old varieties, the supply shift can easily be measured, without the complicating process of calculation. In addition, (3) does not require any specific functional form, in order to calculate a percent horizontal shift. Neither specific elasticities of demand nor supply are needed. As long as the technical change is associated with yield improvement, a horizontal shift induced by agricultural research can always be measured with adoption rates and yield gains of new varieties.

However, we need the information on supply elasticity to convert a horizontal shift to a vertical shift. By definition, a horizontal shift is,

$$(4) \qquad J = \frac{dQ^s}{Q^s} = \left(\frac{dQ^s}{dP} \bullet \frac{P}{Q^s} \right) \times \frac{dP}{P} = \varepsilon K,$$

where ε is the elasticity of supply and K is a vertical shift in percentage term. That is, the horizontal shift can be expressed in terms of a vertical shift using the relationship of (4), once a horizontal shift is measured. As seen in (4), when a supply shift is expressed

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[6] If (3) is applied, the supply shifts in the cases of Griliches (1958), Ayer and Schuh (1972), and Akino and Hayami (1975) are not correct. For example, the horizontal shift in Griliches is calculated as $J = 0.9/(1 - 0.13 + 0.13 \times 0.9) = 0.912$ because $\delta = 0.13$ and $h = 0.9$.

by a vertical shift, the magnitude of K is very sensitive to the change in the supply elasticity because $K = J / \varepsilon$[7].

Measuring Research Benefits

Applying the above formula, research benefits are measured. For simplicity and comparison, the internal rate of return (IRR) and the benefit-cost ratio (B/C ratio) are presented in Table 1. We have very high internal rate of returns. The internal rate of return of 229% implies that 1 dollar spent on research, on the average, earns 2.29 dollars per year from the first year to the last year. These results are much higher than the results observed in other studies. For example, Griliches (1958) estimated the IRR as 35-40% for hybrid corn and Peterson (1967) calculated it as 33% for poultry research. The internal rates of returns of Ayer and Schuh (1972) for cotton research ranged from 77 to 110%, depending on the assumptions. For rice research, the estimates of Akino and Hayami (1975) were between 73% and 75%, and the estimate of Suh (1992) was 81.8%.

Two factors can explain these high estimates. First, the cost of developing high-yielding varieties was very low because the research on high-yielding rice in Korea was performed on the basis of IR 667, already developed by the IRRI. Using the already-developed technology prevented the government from investing more resources on "dry holes," inevitable in the process of research. Second, our estimates are high because we assume that the whole supply shift is induced solely by the *Tong-il* research. However, many factors could have affected the yields and acreage of *Tong-il* rice, as well as research and extension. For example, the yields of *Tong-il* rice are affected by inputs, irrigation, weather conditions, and disease or natural disasters. The *Tong-il* acreage is also

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[7] The sensitivity of a vertical shift was examined by Oehmke and Crawford (2002).

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affected by the expectations on yield differences, market prices, and government purchase price and quantity as well as extension. Thus, if the effects of those factors stated above are taken into account, the actual payoffs to research and extension would be much smaller than the estimates obtained from the rough calculation. In addition, the consideration of government purchase policy, a quality change, involuntary adoption, and an import ban would reduce the payoffs even further.

3.2. Direct Measurement

So far, we implicitly assume that the whole shift of the supply curve is induced by *Tong-il* research and extension. This method is almost always likely to overestimate the research payoffs because all magnitude of supply shifts is not caused by research and extension. That is also the reasons for exceptionally high research returns in agricultural investment.

In the previous section, we showed that supply curve shifts out by the quantity of new varieties, so a J percent horizontal shift is measured by dividing the output of new varieties by total output. The actual horizontal shift expressed with a quantity term, not a percentage term, can be written as follows:

(5) $$Q^T - Q_C^T = Q_T^T = y_T A_T.$$

One of the most important factors in measuring the research benefits is the size of supply shift. According to (5), the supply shift can be expressed in terms of yield and area of new varieties. In general, the yields are not affected by government policies, such as a price support or a purchase program. Rather, the yields are affected by inputs, land quality, weather, diseases and pests, and research. The area is affected by price and yield

differences between new and old varieties, extension, and government policies. If we find the effects of research on yields and the impacts of extension on acreage, it is possible to measure directly the benefits induced by agricultural research.

First, we need to measure the stock of knowledge created by the research because the current fruits of the research are obtained by the knowledge accumulated from the past. The knowledge stock is accumulated exactly by the difference between knowledge not in use and newly-added knowledge by the associated research. Since it is difficult to measure directly the knowledge stock, though, researchers have usually used the aggregated research expenditures as a proxy for the knowledge stock.

In addition, we need to distinguish the research done to develop a new product from the research carried out to maintain or improve one or two features of the developed varieties. The contributions of two kinds of research to the yields of *Tong-il* rice were not the same. In general, the research done in the initial stage has more impacts than the follow-up research. For example, the level of *Tong-il* yields that could be obtained at the farms' level was already determined, though fluctuated, when *Tong-il* was developed. In other words, the high yields of *Tong-il* rice did not arise proportionately to the investment on *Tong-il* research. The potential yields of *Tong-il* rice already reached a certain level and the actual yields of each year fluctuated because of several other factors, such as inputs, land quality, weather conditions, and the follow-up research. Thus, the aggregated effects of research are the sum of effects of the initial research and the follow-up research.

The potential yields of *Tong-il* rice were assumed to be the mean of the realized yields of *Tong-il* rice. The mean of *Tong-il* rice from 1972 to 1991 was 475.80kg/10a. The effects of the follow-up research were estimated through a regression analysis. The

deviations of the yields subtracted from the mean, instead of actual yields, were built as the dependent variable of the regression. An aggregated research expenditure variable (R_t), included as a right-hand side variable in the regression, is calculated from the inverted V-shape lag profile. The research effect is assumed to continue to 7 years[8].

Besides the research expenditure variable, other variables (rain, temperature, irrigated area, and affected area by disaster) that cause the supply curve to shift were put in the regression equation. To catch the effect of the lowest level of harvest in 1980, a dummy variable was inserted as well. The result of the regression is:

$$(6) \quad y_T - mean = -284.82 - 0.014712R_t + 1.6790(Fert) - 0.25495(Rain) + 11.815(Temp)$$
$$\quad\quad\quad (248.4) \quad (1.182) \quad\quad (1.689) \quad\quad\quad (0.05494) \quad\quad\quad (8.931)$$

$$+ 0.031503(Irri) + 0.21353(Disaster) - 164.12D_{80},$$
$$(0.05234) \quad\quad (0.6752) \quad\quad\quad (41.87)^{***}$$

$$n = 20, \; R^2 = 0.8096, \; D.W. = 1.4882,$$

where *, ** and *** imply that the estimate is significant at 10%, 5% and 1%, respectively. The values in parentheses are standard errors.

The estimate of the follow-up research turns out to be insignificant. This result entails that the additional research did not contribute to the increase in yields of *Tong-il* rice. The follow-up research, in fact, was focused on the quality improvement of *Tong-il* rice rather than the yield enhancement. Thus, the insignificant estimate of research is compatible with the *Tong-il* history. Based on the regression results, the mean was taken as the total effects. There are no significant estimates among other variables except for D_{80}. The significant estimate of D_{80} implies that the *Tong-il* yields of 1980 was 164.12 kg/10a lower than the mean of yields.

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[8] For the detailed discussion on lag structure of research expenditures, see Alston *et al*., p.179, 1995.

We need one more regression equation: an area response. When farmers make production decisions in the spring, farmers consider output prices, yields, and government prices and quantities. However, market prices, yield differences, and government's prices and quantities are not known until harvest. Thus, farmers have to make production decisions on the basis of their expectations on those variables. Most of the available information that farmers can use at the time of planting is the past experience and the past data on prices and yields.

There are several ways to form the expectations, such as naïve, extrapolative, adaptive, and rational expectations (for detail, see Nerlove and Bessler, 2001). For simplicity, we present here the case of naive expectations. The regression result is,

$$(7) \quad A_T = -343,020 - 2.9884 E_{t-1}[(P_T - P_C)_t] + 296.81 E_{t-1}[(y_T - y_C)_t] + 0.44270 E_{t-1}[(Q_{T,G})_t]$$
$$\quad\quad (102,400)^{**} \quad (3.219) \quad\quad\quad\quad (518.2) \quad\quad\quad\quad\quad (0.05494)^{***}$$

$$\quad\quad\quad + 12,419(Ext)_t - 15,915 D_{72-80},$$
$$\quad\quad\quad\quad (2,693)^{***} \quad\quad (73,290)$$

$$n = 19, \ R^2 = 0.9301, \ D.W. = 1.7114,$$

where *, ** and *** imply that the estimate is significant at 10%, 5% and 1%, respectively. The values in parentheses are standard errors.

We have the robust estimate of extension. The robust estimate of extension entails that extension contributed to the increases in *Tong-il* acreage. The acreage affected by extension is calculated by multiplying the extension expenditures by the estimate of extension obtained in the area regression equation. The differentials of price and yield proved not to affect the *Tong-il* areas.

One interesting result is the estimate of the government quantity. According to traditional theories, government price and/or government quantity do not affect the market situation. However, our estimate contradicts the traditional theory. Unlike the

traditional theory, *Tong-il* quantities purchased last year by the government affects this year's *Tong-il* areas. This result will be discussed in detail in the section of government purchase policy.

The IRR and the B/C ratios estimated in the directly-measured way are presented in Table 1. The B/C ratios drop, while the IRR rises. The B/C ratios decrease because we measured the effects of only research and extension on *Tong-il*'s yields and adoption rates. The decreases in the B/C ratio are affected by the changes in the adoption rates rather than the changes in yields, because the potential yield is assumed to be the same as the mean of the actual yields. The IRR rises because the adoption rates of the early years obtained from the regression were higher than the actual adoption rates. High adoption rates lead to high research benefits.

3.3. Spillovers

The other factor we should take into account is the spillovers. In the *Tong-il* case, some researchers pointed out that some production technology developed for *Tong-il* was also applied to conventional rice, leading to the enhancement in the yields of non-*Tong-il* rice. For example, Ju (1980) reported that the yields of conventional rice increased substantially through the application of *Tong-il* technology to conventional rice. If we do not consider the spillovers in spite of the obvious evidence, the research benefits measured under the assumption of absent spillovers are likely to be underestimated.

Let us divide the yields of conventional rice into two parts: yields contributed by research, inputs, and weather, and yield increases caused by the spillovers from *Tong-il*

rice. Let y_C^* be yields with the spillovers and s_C be yield increases due to the spillovers.

Then, the actual yields of conventional rice are:

(8)
$$y_C^* = y_C + s_C.$$

Then, the percentage change in yields is:

(9)
$$\delta = \frac{y_T - y_C^*}{y_T} = \frac{y_T - (y_C + s_C)}{y_T} = \frac{y_T - y_C}{y_T} - \frac{s_C}{y_T} < \left(\frac{y_T - y_C}{y_T} \right).$$

Thus, if the yields effects of the spillovers are not subtracted from the actual yields, the estimates are likely to be underrated, as long as s_C is positive. The spillover effects should be appropriately dealt with, because there would not have been spillovers, if *Tong-il* rice had not been developed.

There is no easy way to measure the spillover effects because the spillover effects are not observed directly. Due to the difficulty in direct measurement, the spillover effects are here estimated through the residuals. The yield of conventional rice is a function of inputs, irrigation, weather, disaster, research, spillovers from the other varieties, and unobservable disturbances. Thus, if some systemic effects are still observed even after the effects of other variables are eliminated, the remaining effects are likely to be the spillovers. However, the method of a dummy variable is almost always subject to the criticism that other factors unknown so far could affect the estimate of a dummy variable as well as the factor of our interest. In fact, we cannot exclude completely the possibility that other factors may have affected the yields of conventional rice. However, if we can exclude the effects of other variables as many as possible, we can get an *approximate* estimate for the spillovers.

To find out the effects of the spillovers, a regression was run. The variables are the same as specified before. The results of the regression are,

$$(10) \quad y_C = 365.35 + 0.26892R_t - 1.7799(Fert) + 0.59887(Temp) - 0.068476(Rain) - 0.093159(Irri)$$
$$\quad\quad\quad (92.79)^{***} \quad (0.3566) \quad (1.689) \quad\quad (3.296) \quad\quad\quad (0.04575) \quad\quad\quad (0.03912)^{**}$$

$$\quad\quad + 0.070394(Disaster) + 8.1300(Time) - 123.46D_{80} - 25.740D_{76-91},$$
$$\quad\quad\quad (0.1473) \quad\quad\quad\quad (2.318)^{***} \quad\quad (19.03)^{***} \quad (11.53)^{**}$$

$$n = 29, \ R^2 = 0.9434, \ D.W. = 1.5504,$$

where *, ** and *** imply that the estimate is significant at 10%, 5% and 1%, respectively. The values in parentheses are standard errors.

In the regression, research expenditures on conventional rice, fertilizer, temperature, and rain do not explain appropriately the changes in the yield of conventional rice. The estimate of the trend variable is significant, while the estimate of research expenditures is not significant. The trend variable usually explains the effects of yield increases caused by the technical improvement of farmers from the past cumulative experience and maintenance research of government or related research institutions. The results of regression tell us that the yields of conventional rice rose due to the cumulative knowledge from farmers' experiences, rather than the research. The estimate of the dummy for 1980 is also significant.

Our attention here is paid to the dummy for 1976-1991. The significant dummy variable entails that there are some other factors that affected the yields of conventional rice, besides traditional factors that generally affect production. If the dummy can be interpreted as the spillover effects of *Tong-il* technology, the regression results suggest that 25.74 kg/10a in conventional rice yields is obtained from *Tong-il* technology. However, it is still not certain whether the yield gains came from the spillovers of technology developed for *Tong-il* rice.

Some evidence exists that supports both the direct and indirect spillovers of *Tong-il* technology. Because *Tong-il* rice had never been introduced before and growers had no experience with *Tong-il* rice, new innovations associated with seeding and planting *Tong-il* rice, and new methods related to applying fertilizers and chemicals were developed. According to some literature (Ju, 1980; Kim, 1978), the innovations developed for *Tong-il* rice were also spread to and adopted by the farmers who grew conventional rice. One of the most important innovations was the introduction of plastic film to cover the seed beds so that seeds could be protected from cold weather at night (Kim 1978; Seo 1983). The introduction of plastic film lengthened the growing period of rice, resulting in more output at harvest. A few years later, most seedbeds were covered with plastic film[9].

There also exists some indirect evidence to support the spillover effect. *Tong-il* required good quality of paddy lands with good irrigation systems to produce high yields. High yields were accomplished only when supported by a stable water supply and high temperatures (Shim and Lockwood 1975; Kwon 1974). Lots of good quality paddy land was switched to *Tong-il* rice. Thus, the adoption of *Tong-il* must have been negatively linked to the yields of conventional rice. Despite the negative impacts, the yields of conventional rice continued to increase over time. This may be indirect evidence of the spillovers because the yields of conventional rice must have fallen if a lot of paddy plots with good quality were switched to *Tong-il* rice.

The consideration of the spillovers slightly increases the research benefits, compared to the case where the spillovers are not taken into account. Since the expenditures are not affected by the spillovers, the net present values rise. The increased

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[9] The rate of seedbeds covered with plastic film was 27% in 1972. The rate continued to rise to 38% in 1974, 56% in 1975, 65% in 1976, and 81% in 1977 (Kim, p.187).

net present values lead to a rise in the B/C ratio. The B/C ratio rises slightly from 128 to 132 with a 5 percent external rate of interest and from 125 to 129 with a 10 percent external rate of interest. The IRR, however, does not change at all.

IV. Measuring Research Benefits Considering Government Purchase Policy

In general, market prices are not affected by government purchase policies under a certain market price because the total demand for the product is fixed in the short run. Most of the product purchased by the government is usually released back to consumers in some form, such as resale to market, assistance to the poor, food for the military, and food aid to victims of disaster. Market prices are not still affected when the government increases purchase quantities, because the increased quantity of the government purchases represents a portion of market demand, rather than new demand. That is, government purchase policies do not create new demand in rice market, unless the government throws away or exports the purchased product. In the short run, market price is independent of the government's purchase policy.

The historical observations of the rice purchase program of Korea, however, show that government purchase policies are closely related with production. In Korea, the government used purchase policies to accelerate production in the 1970s and 1980s. The government continued to raise the supported price and to increase the government quantity purchased from farmers. Government prices were also kept higher than market prices in most periods. As seen in Figure 2, the quantity of government purchases moved along with total production over the whole period. These trends suggest that the

government purchase policy and total output are not independent of each other[10]. In such cases, it is not appropriate to apply the traditional model to government purchase policy.

Figure 2. Trends of Rice Production and Government Quantity, 1965-2003
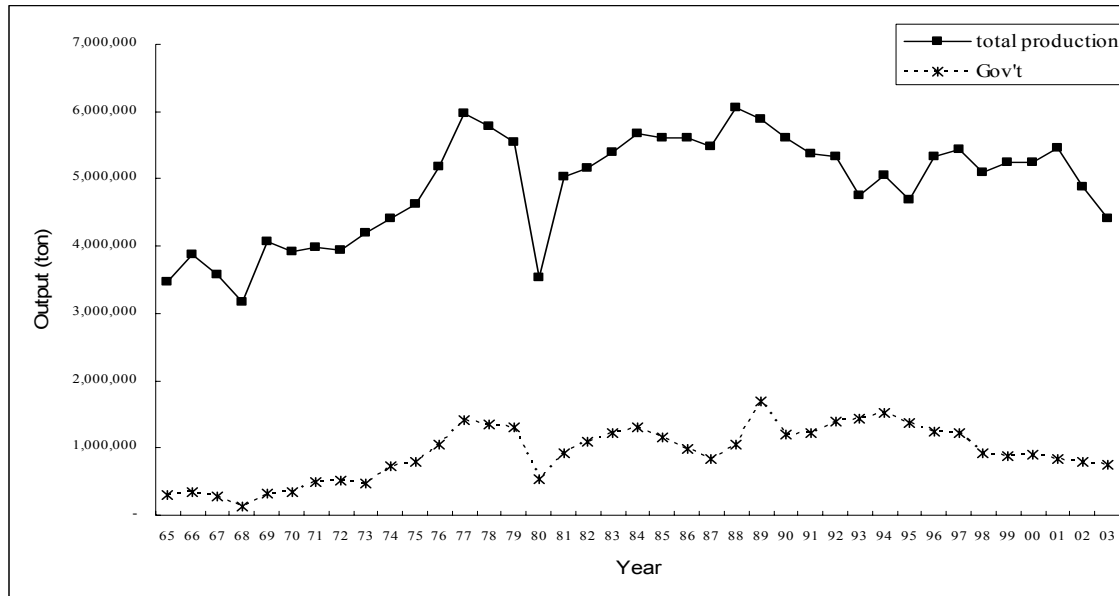

There are three possible ways that government purchase policies can affect the market: proportionate purchase of output, stock, and price uncertainty. The proportionate purchases can affect the market because farmers will get higher incomes as they produce more. However, as seen in Figure 3, the government quantity in the Korean purchase policy was not been determined in such a way. The share of government quantity in total production fluctuated quite a bit, rather than remaining stable. Putting it another way, the

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[10] The similar trends of government quantity and output were also observed in China. The Chinese government kept a quota policy on rice for several decades. Unlikely the Korean purchase policy, government prices or prices for quota rice were set below market price. Hence, the Chinese quota policy was a kind of lump-sum tax, rather than a lump-sum subsidy. According to Wang *et al.* (2003), the level of quota moved along with the level of total production between 1970 and 1984. After 1984, quota decreased substantially, while production continued to increase. However, the trends of production and quota continued to move together, though the difference between production and quota became larger than before. For detail on the Chinese quota policy and figures of the trends, see Wang *et al.* (2003).

quantities purchased by the Korean government were not determined proportionately to the level of total output. Thus, it is not appropriate to apply this model to the Korean purchase policy.

Figure 3. Share of Government Quantity in Total Production, 1965-2000

Government Share
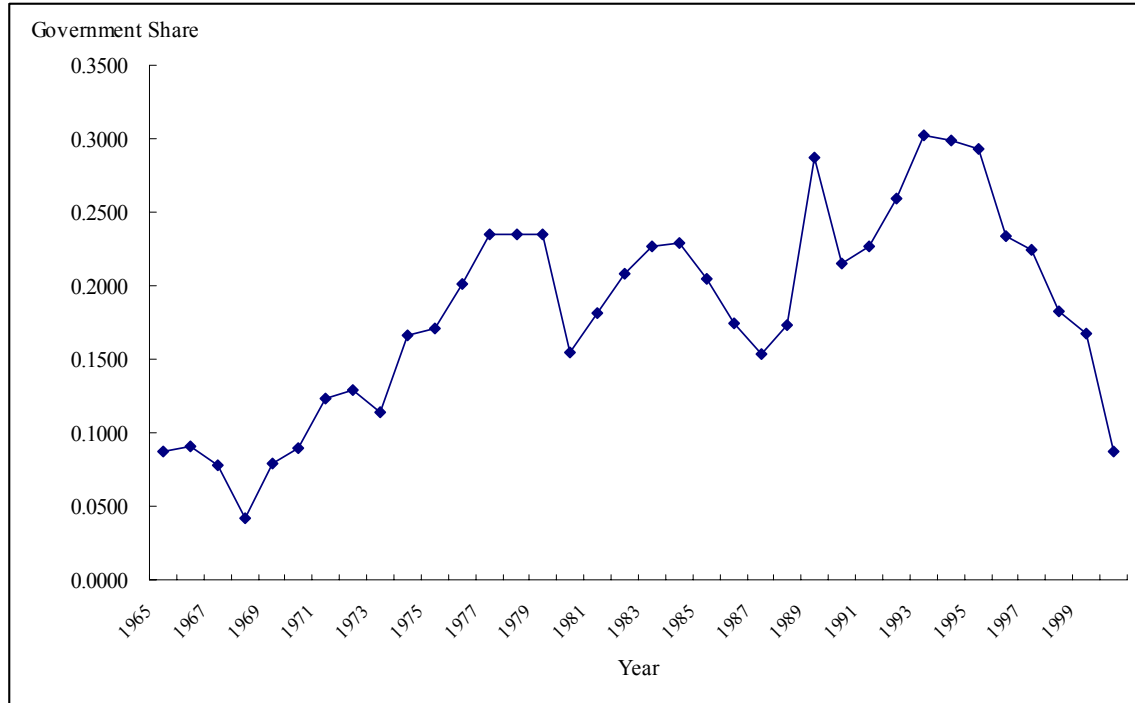
The uncertainty of price is known to have a negative effect on production. Sandmo's article (1971) has been cited as one of the first papers that showed the negative relationship between price uncertainty and its effects on production. Sandmo showed that the expected market price is larger than a competitive firm's marginal cost. With a smaller marginal cost than the expected market price, Sandmo said that "under price uncertainty, output is smaller than the certainty output" (p.66-67). In addition, Sandmo demonstrated that the variability of price also affects production. A risk-averse firm

would reduce its production if the variability of price increases. Sandmo's idea can also be applied to our model of government purchase policies.

Suppose that the utility function satisfies the von Neumann-Morgenstern theorem and that the utility function is bounded from the above. In addition, assume that government price and quantity are given exogenously. A risk-averse farmer now maximizes her expected utility by choosing the quantity to be sold at market. The expected utility maximization problem of the farmer in our model with respect to Q_M is[11],

(11)
$$\max E[U(P_G Q_G + P Q_M - C(Q))].$$

The first and second order conditions are,

(12)
$$E[U'(\pi)(P - C'(Q))] = 0,$$

(13)
$$D = E[U''(\pi)(P - C'(Q))^2 - U'(\pi)C''(Q)] < 0.$$

Let us examine the effects of a small increase in government quantity on total output. Since total output is the sum of quantities to be sold to the government and sold at market, total effects of government quantity are,

(14)
$$\frac{\partial Q}{\partial Q_G} = \frac{\partial (Q_G + Q_M)}{\partial Q_G} = 1 + \frac{\partial Q_M}{\partial Q_G}.$$

Applying the implicit function theorem, we have

(15)
$$\frac{\partial Q_M}{\partial Q_G} = -\frac{1}{D} E[U''(\pi)(P - C'(Q))(P_G - C'(Q)) - U'(\pi)C''(Q)].$$

Thus, (14) becomes

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[11] Holthausen (1979) analyzed the effects of hedging of competitive firms under price uncertainty. The model of Holthausen is very similar to our model, in that a firm in the Holthausen model may either sell its output in the future at a random market price or sell forward at a certain price. However, our model is different from the Holthausen model because the certain price in our model is set by the government, so the government price can be set at any level, depending on what the motives of the government are. On the other hand, the hedging price in the Holthausen model is determined at market, so hedging price and market price tend to converge. This convergence of prices cannot take place in a government purchase model.

(16)
$$\frac{E[U''(\pi)(P-C'(Q))^2] - E[U''(\pi)(P-C'(Q))(P_G-C'(Q))]}{E[U''(\pi)(P-C'(Q))^2 - U'(\pi)C''(Q)]}.$$

Considering that the denominator of (16) is negative, it is certain that the sign of the above equation (16) depends entirely on the numerator. The first term of the numerator is definitely negative. If the second term of the numerator is negative, (16) obviously becomes positive. If we assume the decreasing absolute risk aversion, we can show that the second term is also negative. In other words,

(17)
$$E[U''(\pi)(P-C'(Q))(P_G-C'(Q))] \geq 0.$$

This proves the statement that a rise in government quantity increases output of risk-averse farmers under price uncertainty. That is, government purchase policies are no longer independent of output when there exists the uncertainty of market price. According to Sandmo, risk-averse farmers produce less under price uncertainty than certainty. However, the above result suggests that risk-averse farmers would increase output level if the government purchases a fixed quantity at a fixed price from them. Government purchase policies can increase the reduced output caused by price uncertainty to a certain level. Whether the increased output is less than or the same as the output under price certainty, depends on the degree of risk aversion of farmers.

The government purchase policy, as seen above, is not independent of output. The dependence of output on government purchase policies indicates that the whole shift of supply curve is not induced by research and extension. In other words, a portion of the supply shift observed at market was caused by the government purchase policy. Thus, the effects of the government purchase policy have to be subtracted from the research benefits, in order to get more accurate estimates.

The estimate of government quantity was taken from the results of naïve expectations in (7). It is assumed that the adoption rates of *Tong-il* rice do not change. After subtracting the quantity caused by government purchase policy from total production, research benefits are recalculated. The results are shown in Table 1 for comparison. When government purchase policy is considered, the research benefits expressed in terms of the IRR and the B/C ratio decrease slightly. That is, the consideration of government purchase policy reduces the research benefits but the decline is not substantial.

V. Research Benefits Considering a Quality Change

We have, so far, dealt with two different qualities of rice as a single product with no quality differences. However, *Tong-il* was a quality-degrading technology, despite its yield improvement and savings. High quality rice in Korea should be sticky, besides general quality characteristics, such as shape, chalkiness, the percentage of whole kernels, and fragrance. *Tong-il* rice was much less sticky than conventional rice, so *Tong-il* was recognized as low-quality rice.

The quality difference between two rice varieties was evaluated at market as the difference in price. *Tong-il*'s prices were always below conventional rice's prices. In general, the price differential at market between conventional and *Tong-il* rice was around 15 percent. This differential indicates that consumers get a 15 percent lower utility from *Tong-il* rice than conventional rice, even though the same quantity is consumed. The difference in utility per unit is a loss caused by the inferior quality of *Tong-il* rice. The gross benefits of research would have been higher if there had not been

a quality change in *Tong-il* rice. This loss has to be subtracted from the total research benefits of *Tong-il* rice. Subtracting the loss caused by a quality change from the total benefits will provide a more correct measure of the social benefits of agricultural research invested in *Tong-il* rice.

If we assume that *Tong-il* and conventional rice was perfect substitutes in consumption and that the portion between two varieties is independent of price changes, we can deal with two different qualities of rice like a single product in an integrated model. Further, a quality change can be represented by a shift in demand, in that a quality change of a product is evaluated through price at market by consumers, not producers.

If the quality of *Tong-il* and conventional rice is the same, total rice demand is

(18)
$$Q^d = h'Q_T^d + (1-h')Q_C^d = Q_C^d,$$

where Q^d, Q_T^d, and Q_C^d indicate total demand, demand for *Tong-il* rice, and demand for conventional rice, respectively. h' is the share of *Tong-il* rice in total production. However, *Tong-il* rice was inferior in quality to conventional rice and the low quality was reflected by the price difference. The price differential calculated from the actual prices is, on average, 17.1 percent and the scale factor is 0.854. In other words, consumers do not distinguish between *Tong-il* and conventional rice if one unit of *Tong-il* rice is traded with 0.854 units of conventional rice. This implies that 1.171 units of *Tong-il* rice has to be given up to get 1 unit of conventional rice. Applying the discount factor, market demand is

(19)
$$Q^d = h'Q_T^d + (1-h')Q_C^d = (0.854h'+1-h')Q_C^d = (1-(1-0.854)h')Q_C^d$$

Thus, the demand with a quality change is below the original demand curve without a quality change. From (18) and (19), a horizontal shift caused by a quality change is

measured as $J' = (1 - 0.854) \times h'$, where J' is a horizontal shift in the demand curve. Once the horizontal shift is measured, a vertical shift in the demand curve can also be measured, using the following relationship,

$$(20) \qquad J' = \frac{dQ^d}{Q^d} = \left(\frac{dQ^d}{dP} \bullet \frac{P}{Q^d} \right) \times \frac{dP}{P} = \eta K',$$

where η is demand elasticity and K' is a vertical shift in the demand curve.

The results of the subtraction of losses caused the quality change are presented in Table 1, with other results. The consideration of the quality change decreases the B/C ratios considerably, while the IRRs fall slightly. The small change in the IRR is induced by the time structure of research benefits because of the large magnitude of research benefits accrued in the early years.

Table 1. Research Benefits in terms of IRR and B/C Ratio

			Estimation Method ($\eta = -0.3$, $\varepsilon_1 = 0.5$, $\varepsilon_2 = 1.0$)		
			Rough Estimation	Direct Estimation	Considering Spillovers
IRR (%)		Case I[1]	229	255	255
		Case II[2]	224	249	249
		Case III[3]	210	241	241
B/C Ratio	r=0.05	Case I[1]	170	128	132
		Case II[2]	142	109	112
		Case III[3]	74	41	44
	r=0.10	Case I[1]	154	125	129
		Case II[2]	128	107	110
		Case III[3]	67	46	49

Note: 1. research benefits estimated without considering other factors.
　　　 2. research benefits estimated, considering government purchase policy.
　　　 3. research benefits estimated, considering government purchase policy and a quality change.

VI. Conclusion

In this paper, we measured the net returns to agricultural research on *Tong-il* rice in such a way that the effects of other factors were eliminated one by one, in order to get more accurate estimates. When measured without other complicating factors, the research payoffs were relatively high. However, research benefits decreased as other factors were taken into account. In particular, the B/C ratios fell substantially when other factors were considered. So far, the research benefits of *Tong-il* innovation have been known to be very high (Suh, 1992). However, the actual welfare gains turned out to be low when all the losses induced by the introduction of *Tong-il* rice were subtracted. In addition, the payoffs will decrease even further if the effects of involuntary adoption and an import ban are considered.

During the measurement of the research benefits, we brought forward several innovations. First, we showed that a horizontal shift induced by research can easily be measured if the research is associated with the enhancement in yield of a crop. In this case all information we need is just yield gains and adoption rates. We also suggested that the actual research benefits mixed with other factors can be separated from other factors, leading to more accurate estimates. We also demonstrated that government purchase policy has a positive effect on production under price uncertainty. This result contradicts the traditional theory because government purchase policy has been considered as a lump-sum tax or subsidy in the traditional theory. We showed as well that the shift in the demand curve caused by a quality change can be measured if the information on the price differential of two products at market is known.

One important implication of this paper is that the actual welfare gains would not be so high, if the innovation is introduced with market-distorting policies. Considering that an innovation in developing countries is adopted through a similar process of the *Tong-il* case in Korea, the findings of this paper have much implication to developing countries that have already taken, or will take a similar path of the Korean case.

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