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'Second-generation' MVs and the evolution of the Green Revolution: the case of Central Luzon, 1966–90

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Abstract

By now new modern rice varieties (MVs) with multiple pest and disease resistance have completely replaced early MVs, such as IR5 and IR8, except in a few areas of Asia. This study attempts to identify the changing impacts of 'first-generation' and 'second-generation' MVs on productivity in rice farming by estimating the yield function, while correcting selectivity bias arising from the choice of varieties. For this purpose, we used farm-level survey data collected for eleven cropping seasons in Central Luzon in the Philippines from 1966 to 1990. We found that while the yield advantage of first-generation MVs over traditional varieties was limited, the yield-increasing effect of second-generation MVs over first-generation MVs was highly significant. In particular, the adoption of improved MVs significantly contributed to yield growth under the irrigated condition and during the dry season. Thus, we conclude that the Green Revolution would not have been revolutionary without the development and the diffusion of second-generation MVs with multiple pest and disease resistance.

1. Introduction

Rice yield in Asia has achieved remarkable growth since the late 1960s due to the widespread adoption of semi-dwarf, high-yielding modern rice varieties (MVs), originally developed by the International Rice Research Institute (IRRI) – a phenomenon popularly known as the Green Revolution. The yield increasing impacts of the MV adoption during the early phase of the Green Revolution have been well documented by a large number of case studies conducted in various parts of Asia in the 1970s (IRRI, 1975; Barker and Herdt, 1985). Rice yield, however, has continued to increase since then (David and Otsuka, 1994; Hayami and Otsuka, 1994). Yet much less is known about the 'evolution' of the Green Revolution.

By now new MVs have completely replaced early MVs, such as IR5 and IR8, except in a few areas of Asia. Those early MVs were highly susceptible to pests and diseases and major production losses occurred occasionally due to their epidemic outbreaks. According to the fertilizer response experiments conducted in the Philip-

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pines (Flinn and De Datta, 1984; Pingali et al., 1990), the yield of earlier MVs was highly unstable and subject to a declining trend. To reduce yield losses, the breeding programs in IRRI as well as in national research institutions have developed varieties resistant to various pests and diseases since the mid-1970s (Khush, 1987, 1989). The experimental data show that those new MVs considerably reduced the downward yield instability, even though they failed to break the record of the highest yield per hectare attained in earlier years. The reduction in the downward yield instability would mean not only a reduction in yield risk but also an increase in expected yield. These observations suggest that the Green Revolution would not have been sustainable without the development and the widespread adoption of 'second-generation' MVs with multiple pest and disease resistance.

In this study, we specifically hypothesize that not only 'first-generation' MVs but also 'second-generation' MVs contributed to the productivity growth. In order to test our hypothesis, we use the farm-level production data in Central Luzon collected by IRRI for eleven crop seasons from the pre-Green Revolution period of 1966 to 1990. While the sample size differed from season to season, a total of 796 samples was collected. Using such a fairly long-term and large data set, we estimate the adoption functions of first- and second-generation MVs and then the rice yield function, while correcting the selectivity bias arising from the choice of varieties, in order to identify the changing impacts of MVs on the productivity in rice farming.

2. Socioeconomic characteristics of sample farms

The analysis of the evolutionary process of the Green Revolution has been hampered by the lack of long-term data recording the relevant production and technology information over time. The data used in this study were collected by a series of field surveys of rice farmers in Central Luzon, in the Philippines, from the wet season of 1966 to the wet season of 1990. This survey is called the Central Luzon Loop Survey, because sample farms are located along a 'loop' of main highway north of Manila through the provinces of Bulacan, Nueva Ecija, Pangasinan, Tarlac, and Pampanga. Given the location of sample farms adjacent to the highway, the Loop Survey data are likely to represent farming conditions with favorable access to market and technology information.

Central Luzun is known as the 'rice bowl' of the Philippines, owing to the relatively favorable natural environments for rice production. The area covered by the Loop Survey is characterized either by shallow rainfed environment largely free from drought and flood or by an irrigated condi-

Table 1
Socioeconomic characteristics of sample farmers in Central Luzon, Philippines

	1966 (W) [a]	1967 (D) [a]	1970 (W)	1971 (D)	1974 (W)	1979 (W)	1980 (D)	1982 (W)	1986 (W)	1987 (D)	1990 (W)
Sample size	91	17	52	13	45	125	78	120	108	60	87
Farm size (ha) [b]	2.1	1.5	2.6	2.1	2.6	1.9	2.1	1.8	1.8	1.7	1.8
Tenure (% area):											
Owner	12.1	0	9.6	0	22.2	7.3	7.7	8.1	8.6	8.3	9.7
Share	74.7	82.4	55.8	61.5	22.2	8.6	12.9	9.0	16.9	13.8	3.6
Lease & CLT [c]	13.2	17.6	34.6	38.5	55.6	84.1	79.4	82.8	74.5	77.9	86.8
Schooling [d]	4.6	5.5	4.5	3.9	5.2	6.5	6.1	6.3	6.5	6.3	6.9
Real wage [e]	6.0	7.9	6.8	5.8	5.6	8.8	8.6	10.2	8.3	7.7	7.5

[a] "W" stands for the wet season and "D" for the dry season.
[b] Refers to average area planted to rice.
[c] CLT refers to the certificate of land transfer.
[d] Pertains to household head.
[e] Nominal transplanting wage per day deflated by paddy price per kg.

tion with gravity irrigation systems. Aside from the presence or absence of irrigation facilities, production environments are relatively homogeneous. The rainfall pattern throughout the year is very uneven. Therefore, while practically the whole area is planted to rice during the wet season, rice cannot be grown during the dry season without adequate supply of irrigation water. The rainfed area is occasionally planted to non-rice crops but mostly lain fallow during this season.

The breakdown of sample farms by season, together with the average farm size planted to rice, tenure distribution, average schooling of household heads, and the real transplanting daily wage deflated by paddy price, are shown in Table 1. The original 91 sample farms in 1966 were randomly drawn. It was attempted to maintain the same sample, but the sample size actually declined due to gradual attrition over time caused by retirement, refusal of interview, or absence during survey visits. Ninety new farmers were added in the 1979 wet season but again the sample size gradually decreased since then. Only in a relatively small number of cases, successors of sample farms were surveyed. [1] The sample size during the dry season was small because only those farms planted to rice during that season were included in the survey.

The average cultivation size of rice farms during the wet season increased from 2.1 ha in 1966 to 2.6 ha in 1970 and 1974, and then declined to about 1.8 ha from 1982 to 1990. These changes in farm size can be explained mostly by changes in sample farms. The cultivation size was smaller during the dry seasons of 1967 and 1971 mainly because of the insufficient supply of irrigation water.

Share tenancy was a dominant form of tenure in 1966/67. Since then, the tenure distribution has experienced drastic changes due to land reform. In Central Luzon, large absentee landlordism prevailed, in which rice *haciendas* consisting of hundreds of hectares were operated by small share-tenants. Gradually the sharp class confrontation between *hacienderos* and share-tenants had developed, which made this region the nursery of agrarian unrest in the 1950s and 1960s. To appease agrarian unrest, the major effort of land reform in the Philippines was concentrated in this region (Hayami et al., 1990). The land reform programs were initially implemented in pilot areas of Central Luzon during the late 1960s, and then in the whole rice and corn areas of the nation since 1972. Under the land reform, share tenants were supposed to be converted either to leaseholders, when landlords owned less than 7 ha of land, or to amortizing owners, when landlords owned more than 7 ha. In the latter case, the Certificate of Land Transfer (CLT) was distributed to eligible tenants, identifying their cultivated areas and promising them the right to purchase the land by paying amortization fees to the Land Bank within 15 years. Both the leasehold rents and annual amortization fees were fixed at about 25% of average net output for three normal crop years before 1972. As Table 1 shows, the proportion of area under leasehold tenancy and CLT markedly increased at the sacrifice of share tenanted area since the late 1960s. [2]

The average schooling of household heads was 4–5.5 years from 1966 to 1974 and increased to more than 6 years from 1979, which would reflect the cohort effect of younger household heads sampled in later years. The real transplanting wage rate has only a slight upward trend with relatively large seasonal fluctuations. It appears that the rate of increase in labor demand failed to outpace the rate of increase in labor supply, even though the MV adoption significantly increased labor demand (Barker and Cordova, 1978; Barker and Herdt, 1985; Otsuka, Gascon and Asano, 1994).

MVs require larger application of fertilizer and other chemical inputs to realize the yield potential. Therefore, it is widely believed in the Green Revolution literature that the new technology favors larger farmers, who have better access to cheap credit markets (e.g., Bhalla, 1979). Share tenants are particularly asset-poor and, hence, have lesser access to credit markets. Thus, it is considered that they are less likely to adopt new varieties than owner cultivators. [3] Moreover, it is widely accepted that because of the disincentive effects of output sharing, share tenants shirk and are slower to adopt innovations (Braverman and Stiglitz, 1986; Newbery, 1975). [4] In the estimation of the MV adoption and rice yield functions, we include farm size and share tenancy ratio as independent variables to test the validity of these popular arguments.

Human capital, or the ability to deal with dynamic disequilibrium, is considered to be the key to the adoption of new technology and efficient resource allocation (Schultz, 1975). We include the schooling of farmers as a variable to represent the farmers' human capital in the regression analyses.

3. Adoption of MVs and changes in rice yields

The yield-increasing effect of MVs is constrained by the environment conditions, particularly by the availability of irrigation water (Barker and Herdt, 1985; Ruttan, 1977; David and Otsuka, 1994). Therefore, irrigation is considered the critical factor affecting the adoption of MVs. As shown in Table 2, ratio of irrigated areas among sample farms during the wet season increased from 60% in 1966 to about 70% in 1979, primarily because of the construction of the Pantabangan irrigation system in 1975, which supplied canal water to the southern part of Nueva Ecija. The irrigation ratio has been 100% during the dry season because rice cannot be grown without irrigation during that season.

In Central Luzon, the adoption of MVs was quite rapid; by 1970 within 4 years after the release of the first MV variety (IR8) in 1966, 67% of farmers adopted MVs. [5] Those 'first-generation' varieties (denoted as MV1), which are defined to include IR5 to IR34 as well as C4 developed by the University of the Philippines, are highly susceptible to pests and diseases. [6] Khush (1987, p. 200), a principal rice breeder in IRRI, states: "Major changes have occurred in the varietal composition and cultural practices for rice during the post-IR8 era. A relatively small number of improved varieties have literally replaced thousands of traditional cultivars, thereby reducing the genetic variability of the crop... Reduced genetic variability, improved cultural practices and continuous cropping with rice have increased the genetic vulnerability of the crop." Rice production in Central Luzon was seriously damaged, for example, by the spread of the tungro virus in the early 1970s. Therefore, the adoption rate of MV1 did not increase appreciably from 1970 to 1974 and rapidly declined from 1974 to 1979.

The rice breeding programs since the early 1970s focused on the development of varieties resistant to blast, bacteria blight, tungro, grassy stunt, brown and whitebacked planthoppers,

Table 2
Irrigation ratio, adoption of rice varieties, and yield by variety in Central Luzon, Philippines

	1966 (W) [a]	1967 (D) [a]	1970 (W)	1971 (D)	1974 (W)	1979 (W)	1980 (D)	1982 (W)	1986 (W)	1987 (D)	1990 (W)
Irrigation ratio (%)	60	100	60	100	53	71	100	72	68	100	60
Adoption of rice varieties (%)											
TVs [b]	100	94	33	8	29	0	0	0	0	0	0
MV1 [c]	0	6	67	92	71	7	10	2	1	2	2
MV2 [d]	0	0	0	0	0	93	90	98	99	98	98
Rice yield (t/ha)											
TVs [b]	2.3	1.9	2.4	1.4	2.1	–	–	–	–	–	–
MV1 [c]	–	1.4	2.6	2.5	2.4	2.5	3.4	4.6	4.4	3.1	5.1
MV2 [d]	–	–	–	–	–	3.8	4.1	4.2	3.6	4.3	3.6
Average	2.3	1.9	2.5	2.4	2.3	3.7	4.1	4.2	3.6	4.3	3.7

[a] "W" stands for the wet season and "D" for the dry season.
[b] Refers to traditional varieties.
[c] Refers to first-generation modern rice varieties.
[d] Refers to second-generation modern rice varieties.

green leafhopper, gall midge, and stem borers (Khush, 1987, 1989). In other words, the breeding approach shifted from the 'offensive' (higher yield) to 'defensive' (lower risk), meaning that in the 1970s, as well as in the 1980s, higher yields were sought through the development of germplasm with multiple resistance to diseases and insects. The first major resistant variety was IR36, released in 1976. All MVs developed after IR36 up to IR76 possess similar resistance, which suggests that it is difficult to identify statistically major resistance traits contributing to productivity growth. These 'second-generation' MVs, denoted as MV2, quickly replaced MV1 by 1979 and were adopted by nearly 100% of the farmers by 1982. [7] The greater profitability of MV2 over MV1 seems to have expanded the adoption area of MVs substantially.

The adoption rate of MVs during the wet season far exceeded the irrigation ratio since 1970. This observation suggests that MVs can be profitably grown not only in irrigated area but also in a shallow rainfed environment, commonly found in Central Luzon. According to a recent study of technology adoption in the Philippines by David and Otsuka (1990), there was no significant difference in the MV adoption rate between irrigated and shallow rainfed environments as of 1987. Whether the presence of irrigation was critical for the MV adoption in Central Luzon, particularly in the early years, is an important empirical question.

Table 2 shows changes in rice yield per hectare by variety. Yield of TVs was about 2 metric tonnes, whereas yield of MV1 was about 2.5 t from 1970 to 1979 when their adoption rates were relatively high or at least non-negligible. [8] So it appears that the yield-increasing effect of MV1 was far from revolutionary. In contrast, the average yield of MV2 over six seasons from 1979 to 1990 was about 4 t, which was significantly higher than those of TVs and MV1 in the 1960s and 1970s. Note, however, that although there were only a few farms growing MV1 from 1982 to 1990, the yield of MV1 was comparable to that of MV2 during that period. Thus, we need a rigorous statistical analysis to identify the yield-increasing effects of MV1 and MV2.

TVs are generally photo-period sensitive and, hence, unsuitable for dry season cropping. The lower yield of TVs in the 1967 and 1971 dry seasons than the preceding wet seasons may reflect such varietal characteristics. In contrast, MVs are characterized by non-photo period sensitivity. In consequence, the yields of both MV1 and MV2 tend to be higher during the dry than the wet season.

Not only the non-photo period sensitivity but also shorter growth duration of MVs contributed to the dry-season rice cropping. [9] Since irrigation water during the dry season is allocated with a schedule for a limited time period in Central Luzon, the shorter growth duration confers the great advantage for the production of rice during this season. Baker and Herdt (1985, p. 27) state: "The impact of reduced growth duration on crop production has probably been as significant as the impact of higher yields." As is shown in Table 3, the rice cropping intensity was about 1.1 for TVs, 1.2 to 1.4 for MV1, and 1.5 to 1.6 for MV2. [10]

Table 3
Rice cropping intensity by variety in Central Luzon, Philippines [a]

	1966/67	1970/71	1973/74	1979/80	1981/82	1986/87
Rice varieties [b]						
TVs	1.17	1.08	1.08	–	–	–
	(91)	(17)	(13)	(0)	(0)	(0)
MV1	–	1.20	1.26	1.44	1.00	2.00
	(0)	(35)	(32)	(9)	(2)	(1)
MV2	–	–	–	1.59	1.59	1.51
	(0)	(0)	(0)	(116)	(118)	(107)

[a] Numbers in parentheses are sample sizes.
[b] The classification is based on varieties grown during the wet season.

These data support the observation of Barker and Herdt.

4. Estimation procedure

Since the farmer's variety choice is endogenous, direct application of the ordinary least squares method (OLS) to the yield function, which includes variety dummies as independent variables, will bias estimates of the parameters. Nevertheless, the OLS has been applied in past studies which estimated the impact of modern rice and wheat varieties on the land productivity (Feder et al., 1985). In order to correct for the selectivity bias, this study employed an estimation method which extends Heckman's (1976) two-step procedure; we applied the probit method to the variety choice function in the first stage and then estimated the yield function in the second stage, while using the inverse Mill's ratio obtained from the first-stage probit. [11] Needless to say, the first-stage probit analysis is of interest in itself.

We demarcated the entire period of our study into three phases: 1966–67, 1970–74, and 1979–90. In the first phase, essentially only TVs were available and, hence, there was no variety choice problem. Farmers faced the choice between TVs and MV1 in the second phase and practically between MV1 and MV2 in the third phase. In order to account for such choice behavior, we applied the probit method for the variety choice functions separately for the second and third phases. In what follows, we outline the estimation procedure.

First, let us define the reduced-form expected profit function by variety as:

$$\pi_i = x'\alpha_i + \varepsilon_i \qquad i = \text{TVs, MV1, MV2} \tag{1}$$

where π_i is the expected profit, x is a vector of exogenous variables, α_i is a vector of parameters, and ε_i is a disturbance term. The reduced-form ex-post yield function, after the choice of variety is made, is expressed as:

$$Y_i = z'\beta_i + \eta_i \qquad i = \text{TVs, MV1, MV2} \tag{2}$$

where Y_i is rice yield per ha, z represents a vector of exogenous variables affecting rice yield, β_i refers to a vector of parameters, and η_i stands for a disturbance term. We do not observe Y_i for all the varieties. What we observe is the realized yield of the ith variety given the farmer's prior decision to choose it. We assume that a farmer chooses the ith variety rather than the jth because expected profit of the ith variety is larger, i.e., $\pi_i > \pi_j$. Thus, the conditional expectation of Y_i is written as $E(Y_i \mid \pi_i > \pi_j) = z'\beta_i + E(\eta_i \mid \pi_i > \pi_j)$. Since η_i and ε_i are likely to be affected by common factors, $E(\eta_i \mid \pi_i > \pi_j)$ is non-zero and, hence, the OLS estimate of observed yield on z is inconsistent. We employ Heckman's (1976) lambda or the inverse Mill's ratio as a right-hand side variable to correct for selectivity bias in the estimation of yield function.

While the expected value of yield function in the first phase is expressed as:

$$E(Y_{\text{TVs}} \mid \text{TVs}) = z'\beta_{\text{TV}} \tag{3}$$

the expected values of TV and MV1 yield functions in the second phase are expressed as:

$$E(Y_{\text{TVs}} \mid \text{TVs; (TVs, MV1)}) = z'\beta_{\text{TVs}} + E(\eta_{\text{TVs}} \mid \text{TVs; (TVs, MV1)}) \tag{4}$$

$$E(Y_{\text{MV1}} \mid \text{MV1; (TVs, MV1)}) = z'\beta_{\text{MV1}} + E(\eta_{\text{MV1}} \mid \text{MV1; (TVs, MV1)}) \tag{5}$$

where conditional expectation, $E(\cdot \mid \cdot)$, indicates expected values after the choice of variety is made. For example, the conditional term 'TVs; (TVs, MV1)' indicates that TVs are selected for cultivation from the choice between TVs and MV1. Similarly, the expected values of yield functions in the third phase are shown as

$$E(Y_{\text{MV1}} \mid \text{MV1; (MV1, MV2)}) = z'\beta_{\text{MV1}} + E(\eta_{\text{MV1}} \mid \text{MV1; (MV1, MV2)}) \tag{6}$$

$$E(Y_{\text{MV2}} \mid \text{MV2; (MV1, MV2)}) = z'\beta_{\text{MV2}} + E(\eta_{\text{MV2}} \mid \text{MV2; (MV1, MV2)}) \tag{7}$$

Lee (1978) proposes to estimate a pair of equations like Eqs. (4) and (5) or Eqs. (6) and (7), using the inverse Mill's ratios obtained from the first-stage probit. In our case, however, additional information on the parameters (β's) can be obtained by jointly estimating Eqs. (3) through (7). We exploited this data structure to gain efficiency in the estimates of the β's by 'stacking' these equations. Specifically, we assumed that the β's are different for each variety. Adding corresponding correction terms for sample selection bias to the list of explanatory variables, we estimated the resulting equation by OLS, which is consistent. Since the disturbance term of the system has a heteroskedastic structure, we applied White's (1980) procedure in obtaining standard errors.

5. Estimation results of variety choice function

We estimated the MV1 adoption function (TVs = 0, MV1 = 1) using the data for three cropping seasons from 1970 to 1974 and the MV2 adoption function (MV1 = 0, MV2 = 1) using the data for six seasons from 1979 to 1990. To represent the effect of factor prices, we used the logarithm of the real wage rate for transplanting as an independent variable. [12] We used the irrigation ratio to capture the impact of favorable production environment, and schooling of household head, share tenancy area ratio, and logarithm of farm size to capture the effects of socioeconomic factors. Also included were the lagged MV1 adoption ratio in the neighborhood, which is defined as the average ratio of MV1 adoption by farmers in the province other than the observation farmer in the preceding season, [13] dummy variables to represent experience of adopting MV1 or MV2 in the wet season in the preceding survey year, [14] a dry season dummy, and year dummies. The neighborhood adoption variable is supposed to capture the availability of new technology information for a farmer in each province, whereas the previous MV adoption variables are assumed to control the effect of farmer's prior learning of growing new varieties. Thus, the latter variables can be considered to serve the role of lagged dependent variables. The estimation results are shown in Table 4.

Table 4
Probit estimates of rice variety choice functions

	TVs vs. MV1 (1970–74) [a]	MV1 vs. MV2 (1979–90) [b]
Intercept	−3.94	1.75
	(−1.61)	(0.89)
Irrigation ratio	0.03	0.35
	(0.08)	(1.10)
Ln (real wage)	1.02	−0.45
	(0.77)	(−0.50)
Schooling	0.05	−0.03
	(0.95)	(−0.83)
Share tenancy ratio	−0.41	0.78
	(−1.21)	(1.25)
Ln (farm size)	0.03	−0.13
	(0.01)	(−0.62)
MV1 adoption	4.78 **	−6.13
in the neighborhood	(4.31)	(−1.50)
Previous MV1 adoption	0.12	0.30
	(0.21)	(0.79)
Previous MV2 adoption		1.50 *
		(2.07)
Dry season dummy	0.88	−0.58
	(1.51)	(−1.63)
1974 dummy	−0.69	
	(−1.20)	
1979–80 dummy		1.89 *
		(1.76)
1982 dummy		0.69
		(1.21)
1986–87 dummy		0.21
		(0.46)
Log-likelihood	−48.64	−54.06
Restricted log-likelihood	−64.40	−66.43

Numbers in parentheses are t-values. * indicates significance at the 5% level; ** at the 1% level.
[a] The choice of MV1 is set to be unity. The default year is 1970/71.
[b] The choice of MV2 is set to be unity. The default year is 1990.

Only the neighborhood MV1 adoption ratio is highly significant in the MV1 adoption function (first equation). This indicates that a farmer's decision to adopt MV1 was significantly affected by the availability of new technology information. Yet the coefficient of the 1974 dummy is negative and previous MV1 adoption has no significant coefficient. These results indicate that the adoption of MV1 quickly reached the long-run equilibrium level, i.e., the 'ceiling' in the sense of

Griliches (1957). It may also be the case that because of the decreasing resistance of MV1 to pests and diseases or increased pest population over time, some farmers shifted back to TVs. The coefficient of schooling is not significant. Somewhat unexpectedly, the coefficient of irrigation ratio is not significant either. Contrary to the popular belief, this finding suggests that MV1 was not necessarily more productive in the irrigated condition. A part of the reason may be the widespread adoption of relatively tall MV varieties, e.g., IR5 and C4, suitable for rainfed conditions. Another reason could be that the non-irrigated areas in Central Luzon are shallow rainfed equally favorable for the adoption of semi-dwarf varieties. We will further explore this issue when we estimate the yield function. The coefficients of share tenancy ratio and farm size are also insignificant, indicating that neither share tenancy nor access to financial resources represented by farm size affected the adoption of MV1.

In the MV2 adoption function for 1979–90 (second equation), the coefficient of irrigation ratio is positive but not significant. In this case too, the presence of irrigation is not critical for the adoption of new rice varieties. Unlike the case of MV1, the coefficient of the neighborhood MV1 adoption ratio, which amounts to one minus the neighborhood MV2 adoption ratio, is significant only at the 10% level. It appears that the value of technology information became less important in later years, as farmers had experienced growing early MVs. This interpretation is consistent with the lack of significant effects of farmer's schooling, which is supposed to capture the farmer's ability to deal with the disequilibrium caused by the new technology. In contrast, the coefficient of the previous MV2 adoption dummy is positive and significant. This is likely to be explained by the fact that because of the resistance to pests and diseases the productivity gain of MV2 was 'sustainable' so that the majority of farmers continued to adopt these varieties from 1979. Again, there is no evidence that the tenure and farm size significantly affected the variety choice. The absence of significant effects of these variables is consistent with Ruttan's (1977) generalization of the early Green Revolution experience that neither land tenure nor farm size affected the adoption of MVs.

Overall, explanatory powers of probit equations are poor in term of the significance of the estimated coefficients. This would be because the adoption of both MV1 and MV2 was so fast and widespread within a short period of time that there were relatively small variations in their adoption rates across areas and seasons within the second and third phases. Such rapid shifts of varieties will not be explained, unless MV1 were, or at least were expected to be, far more profitable than TVs, and MV2 was also more profitable than MV1. It could be also argued that the poor fit of the variety choice function is due to homogeneity of rice growing conditions and sample farms in Central Luzon. If this is indeed the case, it would be relatively easy to assess the effects on rice yields of different rice varieties.

6. Estimation results of rice yield function

In the estimation of the yield function, we pooled all the data and estimated both intercepts and slope coefficients separately for the three types of varieties by including interaction terms between variety dummies and other independent variables. [15] The dependent variable is the logarithm of rice yield per ha. The similar set of independent variables used for the variety adoption functions was employed, the difference being the inclusion of the inverse Mill's ratios and the omission of the neighborhood variety adoption and previous MV adoption variables. In this analysis not only slope coefficients but also intercepts are important to identify the impacts of varieties; the intercept terms indicate the production efficiency associated with rice varieties under rainfed conditions, whereas the additional effects of varieties under irrigated conditions are captured by the irrigation ratio. We assumed that the productivity of each type of variety is commonly affected by year-specific factors, which implies that the coefficients of year dummies are common for each variety type. [16] Note that since the estimated equation is reduced form, the estimated coefficients will reflect not only direct but also indirect yield effects of independent variables, e.g., through their effects on fertilizer application. The estimated coefficients are shown by variety in Table 5.

As shown in the first column, the intercept term for TVs is 7.31. On the other hand, the intercept term in the MV1 yield function is 7.83 (second column). Although the difference between the two intercept terms is substantial, it is not significant according to the t-test of the difference between them (see Table 6). This indicates that the yield increasing effect of MV1 under the rainfed condition was limited, at least during our survey years. It may be that the potentially high-yielding effect of MV1 was not realized due to pests and diseases. More significant is the finding that intercept term in the MV2 yield function is far greater than that in the MV1 yield function. In fact, they are significantly different (Table 6). Thus, in all likelihood, the development and the widespread diffusion of MV2 contributed significantly to yield growth, thereby sustaining the Green Revolution.

It is interesting to observe that the coefficient of irrigation ratio is negative, though insignificant, in the TV yield function, whereas it is positive in the MV1 function and significantly so in the MV2 function. These results indicate that irrigation did not increase production efficiency when TVs were grown and that the adoption of MV2 significantly increased the rice yield under the irrigated condition. According to Table 6, the difference in the coefficients of irrigation between TVs and MV1 is weakly significant and the difference between TVs and MV2 is significant. These observations reinforce our hypothesis that the Green Revolution would not have been sustainable without the development and the diffusion of improved MVs.

It is also interesting to observe that the coefficients of the dry season dummy are negative and highly significant for TVs, negative but insignificant for MV1, and positive for MV2. As was pointed out earlier, TVs are photo-period sensitive and, hence, are expected to be lower yielding than MVs during the dry season. The difference in the coefficients of the dry season dummy between TVs and MV2 is highly significant. Furthermore, the difference in the coefficients between MV1 and MV2 is also significant (Table 6). The shorter growth duration of MV2 may have

Table 5
Estimated coefficients of rice yield functions

	TVs	MV1	MV2
Intercept	7.31 **	7.83 **	9.24 **
	(13.06)	(10.96)	(28.87)
Irrigation ratio	−0.02	0.20	0.15 **
	(−0.33)	(1.57)	(2.77)
Dry season dummy	−0.27 **	−0.25	0.09
	(−2.59)	(−1.32)	(1.37)
Ln real wage	0.16	−0.21	−0.51 **
	(0.99)	(−0.79)	(−3.52)
Schooling	0.01	−0.01	0.00
	(1.27)	(−0.64)	(0.34)
Share tenancy ratio	−0.16 *	−0.16	−0.15 *
	(−2.15)	(−1.21)	(−1.91)
Ln (farm size)	−0.01	−0.10	−0.07 *
	(−0.26)	(−1.09)	(−2.03)
Inverse Mill's ratio for TVs (1970–74)	−0.37 *		
	(−2.23)		
Inverse Mill's ratio for MV1 (1970–74)		−0.04	
		(−0.22)	
Inverse Mill's ratio for MV1 (1979–90)		0.44 *	
		(2.29)	
Inverse Mill's ratio for MV2 (1979–90)			−0.61
			(−1.34)
Year dummies [a]			
1966–67		0.19	
		(0.39)	
1970–71		0.47	
		(1.00)	
1974		0.23	
		(0.50)	
1982		0.13	
		(1.47)	
1986/87		−0.11	
		(−1.47)	
1990		−1.23	
		(−1.47)	
R^2		0.317	
F-value		9.442	

Numbers in parentheses are *t*-values.
* indicates significance at 5% level; ** at 1% level.
[a] Coefficients are assumed to be common for the three types of varieties.

Table 6
t-Test of the difference in the selected coefficients in the yield function

	TVs vs. MV1	MV1 vs. MV2	TVs vs. MV2
Intercept	0.52	1.41 *	1.94 **
	(0.57)	(1.81)	(3.01)
Irrigation ratio	0.22	−0.04	0.17 *
	(1.53)	(−0.31)	(1.98)
Dry season dummy	0.01	0.35 **	0.34 *
	(0.05)	(2.93)	(1.68)

Numbers in parentheses are *t*-values.
* indicates significance at 5% level; ** at 1% level.

conferred the advantage of growing MV2 over MV1 during the dry season. These results are consistent with the earlier observation that the adoption of MVs, particularly MV2, is associated with higher rice cropping intensity.

The coefficients of real wage have the expected negative signs only for the MV functions. In particular, it is highly significant in the MV2 function. These results may be taken to imply that MV2 is more labor-using than other varieties, although separate analysis is required to confirm the validity of such inference. Similar to the result of variety adoption functions, the coefficients of schooling are not significant. In contrast, the coefficients of the share tenancy ratio are negative and significant in the TV and MV2 yield functions. It appears that the inefficiency hypothesis of share tenancy is supported by our data. This result, however, is inconsistent with a summary of the existing empirical literature by Otsuka and Hayami (1988), which indicates that yield under share tenancy tends to be equalized with that under leasehold tenancy and owner cultivation. Otsuka, Chuma and Hayami (1992) further argue that the yield under share tenancy tends to be lower in the areas where the tenancy contract is regulated so that efficient contractual arrangements are suppressed. In the case of Central Luzon, share tenancy was regulated by land reform, to a limited extent during the late 1960s and to a considerable extent after 1972. Under such circumstances, the eviction of share tenants was hazardous for landlords, because if the tenants reported the illegal practice to the agrarian reform office, the land could be confiscated and transferred to the tenants. Thus, share tenants might have shirked without the fear of contract termination and other punishments. [17] It is difficult to judge, however, whether the observed lower yield of share tenanted farms is due mostly to the inherent lack of work incentives or due to land reform regulations.

The farm size variable has a negative and significant coefficient in the MV2 yield function. The significantly negative effect of farm size on yield is consistent with the well-known inverse relation between farm size and land productivity observed in India (e.g., Bhalla, 1979). While recent studies identified the difference in the land quality as the major cause for such a relation, some negative relation seems to persist even after correcting for the land quality difference (Bhalla and Roy, 1988; Carter, 1984; Verma and Bromley, 1987). To our knowledge, however, such relation has been rarely reported in Southeast Asia including the Philippines. Moreover, in our case the difference in land quality will be well controlled by irrigation, because the natural environments in Central Luzon are relatively homogeneous. [18] The puzzle is why farm size had a significantly negative effect on yield only in recent years. If the production is less efficient on larger farms, we expect that larger farmers would lease out a part of their land. In Central Luzon, however, new tenancy contracts as well as subtenancy arrangements have been prohibited by law, particularly since 1972. As in the case of the inefficiency of share tenancy, the inefficiency of large farm size may be attributed, at least partly, to the tenancy regulations, which have been effective in more recent years. [19]

The coefficients of year dummies are all insignificant. The two coefficients of the inverse Mill's ratios are significant, indicating that the application of OLS will result in the biased estimation of the effects of varieties on rice yields.

7. Concluding remarks

Using the Central Luzon Loop Survey data collected for a period of more than two decades, this study identified the changing productivity impacts of earlier and improved modern rice varieties. We found that while the yield advantage of MV1 over TVs was limited, the yield-increasing effect of MV2 over MV1 was highly significant. In particular, the adoption of MV2 significantly contributed to yield growth under the irrigated condition and during the dry season. Thus, we may conclude that the Green Revolution would not have been revolutionary without the development and the diffusion of 'second-generation' MVs with multiple pest and disease resistance.

Given the increasing population pressure on limited land resources in many developing countries of Asia, rice supply will not be able to keep pace with growing rice demand in future without continuous improvement of the rice yield. A critical question is whether the Green Revolution can sustain itself by further developing improved varieties. As far as Central Luzon is concerned, there was no indication that the rice yield continued to increase in the 1980s. This may indicate that rice research has fallen into the region of decreasing returns. Considering the fact that Central Luzon area is a forerunner of the Green Revolution in Asia, the yield trend in other areas will, in all likelihood, also reach the plateau sooner or later. In fact, Hayami and Otsuka (1994) argue that the Green Revolution in rice farming is the process by which the technologies developed for favorable rice growing areas in Southeast Asia, particularly in the Philippines, have been transferred to less favorable areas within Southeast Asia and to vastly different production environments in South Asia. In order to sustain the Green Revolution so as to prevent food shortages in the near future, more research resources and further breakthroughs will be required in rice breeding programs.

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Notes

[1] See Herdt (1987) for further details of the sampling procedures.

[2] According to Otsuka (1991) land reform was effectively implemented not only in Central Luzon but also in other favorable rice growing areas in the Philippines. As a result, a substantial amount of income has been transferred to leasehold tenants and CLT holders (Otsuka, Cordova and David, 1992).

[3] For a survey of the literature on the adoption of agricultural innovations in developing countries, see Feder et al. (1985).

[4] See Otsuka and Hayami (1988) and Otsuka, Chuma and Hayami (1992) for recent surveys of the tenancy literature.

[5] Note that in this study we excluded partial adopters of MVs from the analysis in order to apply the probit regression method for the estimation of variety choice functions. The number of partial adopters, however, was very small.

[6] IR 29 and IR34 are also resistant to most of the major pests and diseases and could be included in 'second-generation' varieties. However, their adoption rates were negligible in Central Luzon. See Khush (1987, 1989) for further details on the breeding programs in IRRI and characteristics of various MVs developed.

[7] We also categorized MV2 into earlier and later varieties and performed the regression analysis, but found no evidence to support the superiority of later varieties.

[8] Note, however, that rice yield was reported to be seriously damaged by a series of big typhoons in the 1974 wet season.

[9] Average growth durations are about 155 days for TVs, 130 days for MV1, and 115 days for MV2.

[10] In this table, the rice cropping intensity was grouped in accordance with varieties grown during the wet season. Since the same type of varieties tended to be grown in consecutive wet and dry seasons, such classification does not seem to create any problem. Also note that the data on the cropping pattern in the preceding dry season were collected in the 1974 and 1982 surveys.

[11] In the context of our study, Heckman's method amounts to estimating the second-stage regressions only for adopters of the new technology. See Amemiya (1985, chapters 9 and 10) for a recent survey of the estimation methods to deal with the selectivity bias.

[12] Not all sample farmers employed daily wage laborers for transplanting; some of them employed none and others employed laborers under the piece rate contracts. Since daily earnings per laborer under the piece rate contracts were much higher than the daily wage due to the superior work incentives, they are not directly comparable. Thus, we used the average daily wage deflated by the average paddy price in the province. Note, however, that regional variations in wage rates were relatively small due to interregional migration, as in other areas in the Philippines (Otsuka, Cordova and David, 1990).

13 An interpolation was made to estimate such a ratio using data on two crop seasons for which data are available. We did not use regional dummies in this analysis, partly because their estimated coefficients are insignificant and partly because they are highly collinear with the neighborhood MV1 adoption variable.

14 To construct such dummy variables for MV1 and MV2, we utilized the facts that MV1 was unavailable in 1966/67, whereas MV2 was released in 1976, and that all sample farms were surveyed in the preceding wet seasons except for samples newly added in 1979. For those farms, we used the result of a special survey on the first adoption year of MVs conducted in 1986. We excluded those farms newly added in 1979 but dropped out in 1986 from the analysis.

15 Conceptually the yield function corresponds to the supply function per ha. We dropped the price variables, however, because their estimated coefficients were either insignificant or inconsistent with the theoretical expectation presumably due to very small regional price variations and the use of year dummies.

16 The hypothesis that the coefficients of year dummies are common was not rejected. Furthermore, the differences in intercept terms are stable over time.

17 Another possibility may be that those ex-share tenants who realized higher yields shifted to leasehold and CLT holder status, so that the estimated coefficient of share tenancy dummy is biased downward. This interpretation is consistent with Otsuka's (1991) finding that yield growth and incidence of share tenancy are negatively correlated.

18 In fact, the coefficients of province dummies used in the earlier regression analyses are all insignificant, presumably due to the similarity of production environments.

19 A recent study of Otsuka, Chuma and Hayami (1994) reports that because of the prohibition of tenancy contracts some large farmers in an irrigated village in Central Luzon employed fixed-wage labourers for a crop season or longer, who performed tasks similar to those by tenants and owner cultivators. Due to the weak work incentives under the fixed-wage contract, the production of farms with such labourers were less efficient than farms of tenant and owner operation. The Central Luzon Loop Survey, however, did not collect accurate information on the incidence of this new labour contract.

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