Australian Journal of Agricultural Economics, Vol. 34, No. 2 (August 1990), pp. 132–146

THE MODERN SEED–FERTILISER TECHNOLOGY AND ADOPTION OF LABOUR-SAVING TECHNOLOGIES: THE PHILIPPINE CASE*

CRISTINA C. DAVID and KEIJIRO OTSUKA†
International Rice Research Institute, PO Box 933, Manila, Philippines and Department of Economics, Tokyo Metropolitan University, Meguro, Tokyo 152, Japan

While intervillage differences in the adoption of modern rice varieties (MVs) are explained mainly by environmental variables, rather than by socioeconomic factors, relative factor prices are the most important determinants of the adoption of labour-saving technologies. There is no indication that MV adoption is correlated with the adoption of tractors and threshers as well as cropping intensities. Adoption of direct seeding, however, appears to be associated with MV adoption.

Questions continue to be raised about the equity impact of the modern rice varieties (MVs). MVs developed so far have been more suited to irrigated and favourable rainfed conditions with adequate water control (Barker and Herdt 1985), bypassing the less favourable production environments where farmers are generally poor (Falcon 1977; Ruttan 1977; Lipton 1985). While MVs are divisible and hence scale-neutral, greater liquidity is required to finance the higher demand for fertilisers and other purchased inputs, which may favour larger farmers who have better access to credit markets (Frankel 1971; Bhalla 1979). Moreover, it is often observed that the spread of MVs precedes a wider adoption of labour-saving technologies, for example, tractors, threshers and direct seeding (Jayasuriya and Shand 1985). Thus, even though MV adoption increases labour use per hectare by increasing labour requirements for crop care and harvesting (Barker and Cordova 1978), if MVs induce mechanisation and direct seeding, the net effect may well be labour-saving, thereby adversely affecting the well-being of poor landless households.

Previous studies on MV adoption were mostly carried out during the decade following the introduction of MVs in the mid-1960s (Feder, Just and Zilberman 1985). At that time, investigation of the dynamic processes involved in dissemination of information, learning by doing, and adjustments in the various factor and product markets had not been completed. Adoption behaviour of other technologies associated with MV adoption had been analysed at the same time but mostly in separate studies. An important question, widely recognised yet hitherto unexplored, concerns the degree of complementarity between the various technologies adopted by rice farmers over the past two decades.

*The authors are grateful to Violeta Cordova, Cristina Carpio and Milagros Obusan for invaluable research assistance. We also thank Yujiro Hayami and Sam Fujisaka for their useful comments and suggestions.
†Visiting scientist at the International Rice Research Institute, Manila, Philippines.

In this paper, the factors affecting cross-sectional differences in the present adoption rates of MVs are examined and their effects on fertiliser use and cropping intensity as well as on the adoption of labour-saving technologies are explored based on a case study of the Philippines. Modern rice varieties have been most rapidly and widely adopted in this country. In 1970, within 5 years of its introduction, nearly 50 per cent of rice crop area had already been planted with MVs. By 1980, the adoption rate had reached 80 per cent and since then has largely tapered-off to about 85 per cent in the late 1980s. Our analysis is therefore concerned with long-run equilibrium adoption behaviour as the dynamic diffusion process by now has largely ended.[1] In particular, an attempt is made to identify the reasons why tractors, threshers and direct seeding have been widely adopted in recent years despite their availability even prior to the introduction of MVs.

Production Environment and Sample Villages

The analysis is based on cross-sectional data of 50 villages representing different production environments according to degree of water control, which depends on irrigation as well as on natural conditions such as topography and rainfall patterns. For the purpose of stratification, production environments have been classified into irrigated, favourable rainfed and unfavourable rainfed areas, the last category being further subclassified into drought-prone areas located in hilly environments and submergence or flood-prone areas located in low-lying areas. Irrigated villages are those served by gravity irrigation systems that provide adequate water supply for at least two rice crops per year. Favourable rainfed is defined as shallow rainfed paddy areas which are neither prone to drought nor flood problems in the wet season. The two subcategories representing unfavourable rainfed conditions are so called because flooding, poor drainage or drought conditions are unsuitable for the adoption of MVs. By nature, production environments are exogenous to the villages under examination.

The distribution of sample villages among the three major production environments was predetermined to be equal so that the number of sample villages in the unfavourable areas in the sample is a higher proportion than their actual share in total rice crop area. Unfavourable rainfed areas are generally small pockets of land that have quite heterogeneous environmental characteristics.

Provincial and municipal government officials assisted in identifying the environmental characteristics in their respective areas of responsibility. The villages were then selected randomly from the representative production environments in eight provinces encompassing five geographic regions in the islands of Luzon and Panay (Fig. 1). Village level data on technology adoption, fertiliser use, wages and paddy prices pertaining to the 1986 wet season as well as tenure and other socioeconomic and physical environmental characteristics were then obtained through group interviews of selected knowledgeable farmers in each village. In addition, information was also obtained on technology adoption in 1970 and 1980 in order to gain

[1] In Griliches (1957) terms, differences in 'ceilings' of adoption are explained here.

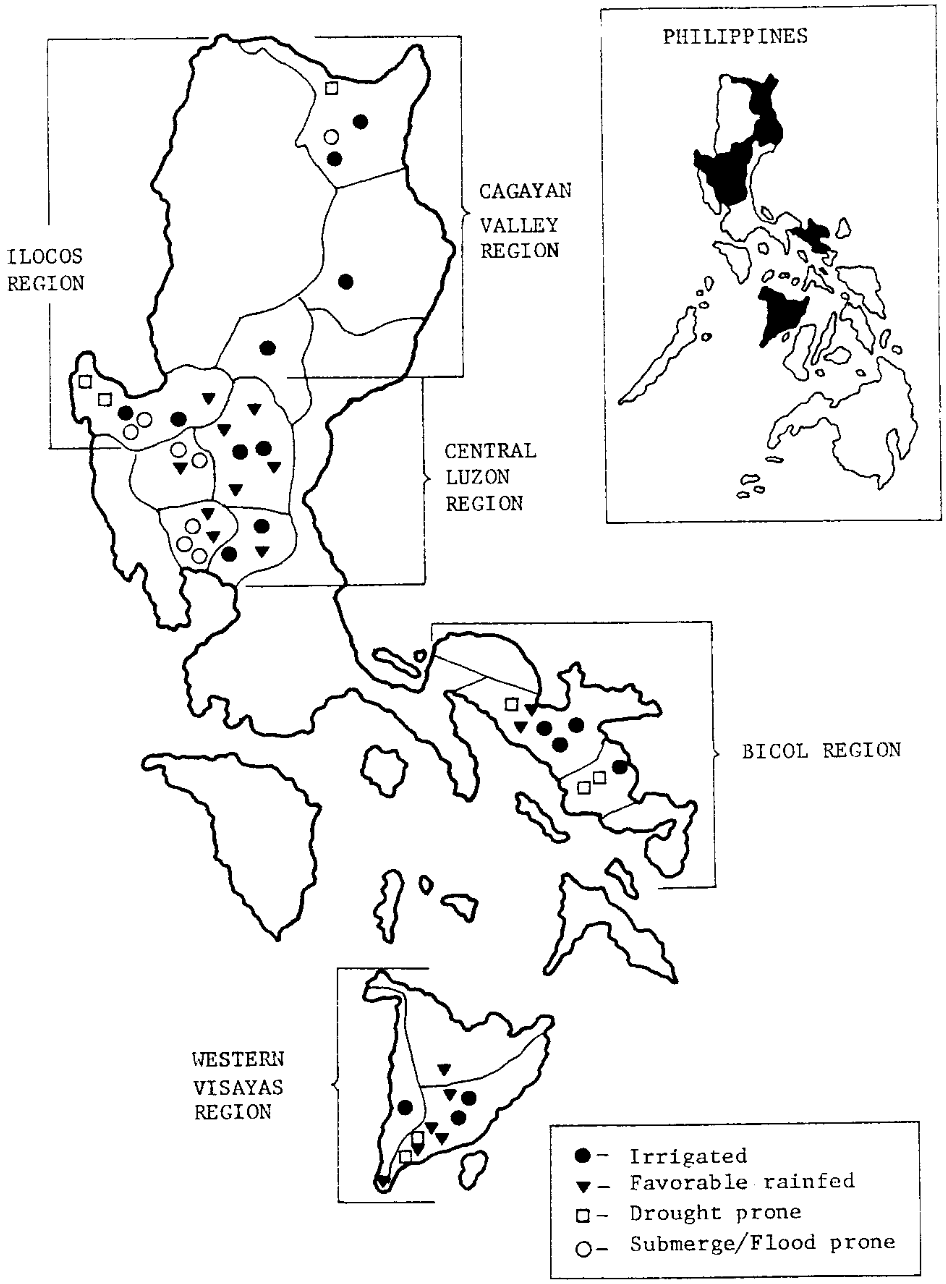

FIGURE 1—Location of Sample Villages.

a historical perspective on the state of current technology adoption, even though such recall data may be less reliable. This was supplemented by region-specific unpublished data on prices of fertiliser and herbicides from the Bureau of Agricultural Economics.

Table 1 shows the number of sample villages, average farm size and the distribution of tenure status by production environment. Farm size is slightly smaller in the drought-prone area but generally similar across

TABLE 1

Farm Size and Tenure Patterns by Production Environment

	Irrigated	Fav. rainfed	Drought-prone	Submergence-prone
No. of villages	17	17	8	8
Farm size (ha)	1·7	1·7	1·4	1·9
Tenure (% area)				
Owner	22	19	68	18
CLT[a]	34	34	9	31
Leasehold	35	34	5	18
Share tenancy	9	13	18	32

[a]Holders of certificate of land transfer.

production environments. On the other hand, the proportion of share tenants, who are supposed to be converted to leaseholders and CLT (certificate of land transfer) owners by land reform, is higher in unfavourable areas.[2]

Technology Adoption

The probability of adoption of a new technology will depend on the difference in profitability between the new and old technologies. The ability of the farmer to perceive the advantage and efficiently utilise the new technology as often measured by education, farming experience and exposure to extension service is considered to be an important determinant of its adoption (Schultz 1975). Data on the average educational level or farming experience of villagers and exposure of a village to extension services are not available. In the Philippines, however, intervillage differences in those factors are relatively small so that their influences on technology adoption particularly in long-run equilibria will tend to be modest. Our analysis focuses on village-specific environmental and market factors broadly determining the profitability of a new technology, that is, the productivity advantage of a new technology, the economic conditions as reflected in relative prices of inputs and outputs, and the institutional structures manifested in farm size and land tenure patterns.

Yield-increasing technology

Trends in the ratio of irrigated area, adoption of MVs, fertiliser use, yields and rice cropping intensity by production environment are presented in Table 2. In 1970, only about 60 per cent of the sample of irrigated villages were actually irrigated; the other 40 per cent became irrigated only as a result of the acceleration of irrigation investments during the 1970s. A small portion of paddy fields in the rainfed areas are irrigated by water pumps and natural creeks.

Adoption of MVs was equally rapid and complete in the irrigated and favourable rainfed areas which suggests that, at least during the wet season, the degree of water control is not significantly different between the two production environments. In fact, in terms of the natural environment, there is no notable difference between the

[2] See Otsuka (1989) for the statistical analysis of determinants of land reform implementation over the 1970–86 period based on the same data set.

TABLE 2

Trends in the Ratio of Irrigated Area, MV Adoption, Fertiliser Uses, and Yields by Production Environment, Wet Season

	Irrigated	Fav. rainfed	Drought-prone	Submergence-prone
% of irrigated area				
1970	58	4	0	1
1980	84	7	1	3
1986	97	8	1	3
% area adopting MVs				
1970	38	29	6	23
1980	89	95	32	47
1986	97	99	33	50
Fertiliser (kg NPK/ha)[a]				
1970	29	27	4	21
1980	88	68	21	50
1986	87	92	34	60
Yield (t/ha)[a]				
Traditional variety				
1970	2·4	2·2	2·3	2·1
1980	–[b]	–[b]	2·4	1·7
1986	–[b]	–[b]	2·1	1·8
MV				
1970	4·1	3·4	2·3	2·5
1980	3·6	3·5	2·6	2·7
1986	3·6	3·3	2·8	2·4
Rice cropping intensity				
1970	148	108	101	91
1980	183	121	103	92
1986	195	123	96	101

[a]Data refer to the wet season.
[b]Observations are too few.

irrigated and favourable rainfed areas. In contrast, adoption of MVs in the unfavourable rainfed conditions was slower and much less complete. In all areas, the rate of MV adoption has essentially levelled off since 1980.

As to be expected, the changes in fertiliser use per hectare over time and its difference across the production environments closely follow the pattern of MV adoption as the yield response of fertiliser is much higher with MVs.[3] Fertiliser application in terms of the sum of N, P_2O_5 and K_2O was about 90 kg/ha in the irrigated and favourable rainfed areas but less than 40 kg/ha in the drought-prone villages and about 60 kg/ha in the submergence-prone villages in the 1986 wet season.

As a consequence of the differential adoption of the MV–fertiliser technology, a significant yield differential has emerged across production environments. In 1970, no significant difference in yields of traditional varieties between favourable and unfavourable rice-growing areas was observed. By 1986, the yield of MVs ranged from 2·4 t/ha in the submergence-prone areas to 3·6 t/ha in the irrigated villages. Traditional varieties that are still widely grown in the unfavourable rainfed areas yield only half as much as MVs in the irrigated areas.

Since MVs have a shorter growth duration and are photo-period-insensitive, it would be expected that they would produce both

[3] Unlike the tall and weak stems of traditional varieties, MVs are semi-dwarf and stiff-strawed, permitting higher fertiliser application without lodging.

an increase in the yield per hectare per season and also an increase in rice production per year through a higher cropping intensity. Rice cropping intensity, however, rose markedly only in the irrigated villages following the increase in proportion of irrigated area. Between 1970 and 1980, there was a small increase in cropping intensity in the favourable rainfed areas located mostly in the Panay Island where, owing to the more even rainfall distribution, the simultaneous adoption of shorter growth duration MVs and direct seeding made it possible to increase cropping intensity.

The technical superiority of MV technology depends on the characteristic of the production environment as the yield advantage of MVs over traditional varieties increases with the adequacy of water control. In turn, physical productivity of fertiliser use and technical feasibility of higher rice cropping intensity may be affected not only by degree of water control but also by MV adoption. It seems reasonable to hypothesise that variables reflecting technical superiority are relatively more important than socioeconomic factors in explaining cross-sectional differences in the long-run equilibrium adoption of MVs, demand for fertiliser and rice cropping intensity. The quantitative importance of price differences is likely to be small because inter-regional differences in fertiliser and rice price are very small compared with physical environmental factors.

Farm size may not critically affect adoption rates of MVs, because both MVs and fertilisers are highly divisible and thus scale-neutral. However, imperfections in credit markets may cause differential adoption of MVs and levels of fertiliser use by farm size. Tenure may not matter since recent theoretical and empirical work on the economics of tenancy strongly suggests that input use, technology choice and productivity are not significantly affected by tenure status (Otsuka and Hayami 1988).

Labour-saving technology

A major question to be addressed by this paper is whether and to what extent adoption of MVs causes adoption of labour-saving technologies. It should be emphasised at the outset that tractors, threshers and direct seeding had already been adopted in the Philippines prior to the introduction of MVs. In Central Luzon during the mid-1960s, tractors were already being used for the cultivation of at least 10 per cent of rice area in the wet season and about 50 per cent in the dry season (Herdt 1987). In the case of mechanical threshers, use of 'tilyadoras' or large threshers began in Central Luzon in the 1920s so that landlords had a better control over the sharing of the crop under share tenancy (Hayami and Kikuchi 1982). Direct seeding had actually been practised in rainfed lowland areas well before transplanting became widely adopted as a method for controlling the weed problem (Imperial 1980).[4] Therefore, the question with mechanisation is not so much the adoption of a new innovation but the appropriate choice of technology from the technology shelf.

Our village level data show an increase in the adoption rate of tractors, threshers and direct seeding between 1970 and 1986 (Table 3).

[4] In this paper, direct seeding refers to wet seeding of pregerminated seed on puddled soils in bunded paddy fields in contrast to dry seeding techniques practiced in upland, unbunded rice areas.

TABLE 3

Trends in Adoption of Tractors, Threshers and Direct Seeding by Production Environment

	Irrigated	Fav. rainfed	Drought-prone	Submergence-prone
Tractor				
1970	37	24	2	13
1980	63	43	17	33
1986	76	56	15	54
Thresher				
1970	28	37	25	28
1980	66	75	34	47
1986	94	95	47	97
Direct seeding				
1970	2	3	8	47
1980	24	33	4	39
1986	33	51	18	29

In the case of tractors, adoption rates are markedly lower than the corresponding rates of MV adoption with the exception of the submergence-prone areas where the rates are comparable. Farm size is relatively higher in submergence-prone areas, which may confer a scale advantage to the use of tractors.[5] On the other hand, the adoption rate of tractors was lowest in the drought-prone areas where farm size is smallest and transportation of machines across sloping and mountainous terrain is more difficult.

The use of 'tilyadoras' actually diminished in the early 1970s as land reform was implemented and double cropping expanded in Central Luzon, making it difficult for the large machines to traverse the wet fields during the wet season. The small axial flow threshers introduced in the mid-1970s, however, spread rapidly throughout the country (Duff 1978). By 1986, adoption of these small threshers was nearly complete in our study villages except in the elevated areas of drought-prone villages where the small farm size and topography of the village makes mechanisation uneconomical.

The resurgence of direct seeding in lowland rice areas was first observed in Panay in the mid-1970s when the technology package that combines shorter growth duration MVs and direct seeding was introduced to increase cropping intensity (Barlow, Jayasuriya and Price 1983). Since the late 1970s, direct seeding began to spread in some parts of Central Luzon simply to reduce labour inputs (Coxhead 1984). Compared to yield-increasing and mechanical technologies, direct seeding is not as widely adopted; neither is it adopted most intensively in the irrigated areas. It is interesting to observe that in the submergence-prone areas, the shift from traditional to MVs accompanied a decline in the rate of adoption of direct seeding.

Although the spread of MVs coincided with the increased adoption of labour-saving technologies, comparisons of adoption levels between the two types of technologies and of the pattern of adoption of labour-saving technologies by production environments do not support the view that MVs caused the wider adoption of tractors,

[5] These villages are mostly located in Pampanga and Tarlac where large four-wheel tractors in nearby sugar farms are being rented out to rice farmers.

threshers and direct seeding. We hypothesise that MV adoption is not a major cause of adoption of labour-saving technology and, further, that socioeconomic factors are relatively more important in explaining cross-sectional differences in tractor and thresher adoption. Because tractors and threshers are substitutes for labour and/or draft animals (Binswanger 1978), profitability of mechanisation depends critically on the relative prices of machine service, draft animals and labour. Machines are, in general, lumpy inputs and thus efficiency gains would accrue to large farmers from higher capacity utilisation, even though contract hiring of machines now commonly practiced may help neutralise the scale advantage. Saving of supervision costs of casual labourers made possible by mechanisation will also be greater for larger than for small farms. In addition, the imperfect credit market may favour the adoption of mechanical technology by larger farmers.

Direct seeding is a cultural practice that involves less time and labour for crop establishment and seedbed preparation than transplanting. To obtain comparable yields with transplanted rice, herbicides for weed control and higher seeding rate per hectare are required. This suggests that differences in the relative price of herbicides and wages affect the adoption rate of direct seeding. However, choice of seeding method is highly dependent on the surface drainage condition and the rainfall pattern (Garrity, Oldeman, Morris and Lenke 1986). Adoption of direct seeding is not feasible under flooded conditions where younger seedlings are easily washed away by flood and the germination rate is low. Direct seeding is also not widely adopted in drought-prone areas because the farmer is reluctant to drain excess water to broadcast pregerminated seeds when the possibility of drought occurring at a critical growth stage is high (Moody 1982). On the other hand, the shorter growth duration MVs because of their excellent seedling vigour and good tillering capacity are the preferred variety for direct seeding under lowland conditions (De Datta 1980). In favourable rainfed areas with more even rainfall distribution or in areas with a year-round supply of irrigation water the time saved from direct seeding in combination with those early maturing MVs may also increase cropping intensity. Cross-sectional differences in the adoption of direct seeding, therefore, will be influenced not only by relative prices but also by the physical environment and adoption of shorter growth duration MVs. In order to determine the factors affecting intervillage differences in the adoption of yield-increasing and labour-saving technologies, adoption functions are estimated econometrically in the next section.

Determinants of Technology Adoption

Adoption functions have been specified with physical environmental variables and socioeconomic conditions as explanatory variables. Because the observational unit, the village, is a relatively small geographical area, purchased input and output prices can be assumed to be exogenous. For the villages under investigation, wage rates can also be assumed exogenous, since they are largely equalised due to interregional labour migration (Otsuka, Cordova and David 1989).

The two-limit probit regression method developed by Rosett and Nelson (1975) is used to explain rates of technology adoption, which are expressed as the percentage of area (from 0 to 100) adopting the technology. Two types of regression equations are specified. The first regression is a reduced form in which only exogenous variables are included as explanatory variables: namely,[6] (1) environmental variables representing the degree of water control, that is, irrigated village dummy (*IRG*), favourable rainfed village dummy (*FAV*), and drought-prone village dummy (*DPRONE*) with the submergence-prone area as control; (2) socioeconomic variables, that is, farm size (*FSIZE*), percentage of area under share tenancy (*ST*) and owner-cultivator (*OWNER*); (3) various input price–paddy price ratios to be defined; and (4) Panay Island dummy (*PANAY*) in order to control for regional difference, particularly in rainfall pattern.[7]

The second regression is a two-stage simultaneous regression in which the predicted value of the MV adoption ratio (*MVR*) derived from the first-stage two-limit probit regression is used for the second-stage regression.[8] In the second-stage regression of fertiliser demand and rice cropping intensity functions, *IRG* is inserted, in addition to *MVR*, in order to separate the impact of irrigation from MVs on fertiliser use and cropping intensity. In the second stage regression of tractors and thresher adoption functions, dummy variables for the degree of water control were omitted since physical productivity of these two machines does not differ significantly according to production environment. Irrigation, however, may promote adoption of tractors and threshers by increasing cropping intensity, because higher cropping intensity may reduce rental costs of machinery by increasing the utilisation rate and raise the cost of maintaining draft animals as the supply of pastureland declines (Day and Singh 1977; Otsuka, Cordova and David 1989). Thus, the predicted value of rice cropping intensity (*RCI*) was included. For direct seeding, the second-stage regression omitted the variables indicating degree of water control assuming that those environmental factors affect adoption of direct seeding through their impacts on MV adoption. In fact, when all environmental dummies are specified together with MVs in the same equation, none of these variables was statistically significant. The predicted value of *RCI* was also included assuming that increasing cropping intensity induces the adoption of direct seeding.

Yield-increasing technology

Regression results of MV adoption, fertiliser demand and rice cropping intensity functions are presented in Table 4. Environmental factors relating to the degree of water control are the only significant variables explaining variations in MV adoption across villages. It is also interesting to find that MVs are equally likely to be adopted in the irrigated and the favourable rainfed villages judging from the similarity of the estimated coefficients of *IRG* and *FAV*. Urea/paddy price ratio (*UREAP*) is not significant. Consistent with many other studies,

[6] To be strict, these regression equations are not truly reduced-form equations because only the few most relevant factor price variables for each equation are selected due to the limitation of sample size.

[7] Aside from these variables, the soil texture variables represented by clay, clay loam and sandy soil were also employed. These variables, however, were insignificant in all regression equations.

[8] For justification of this two-stage procedure, see Judge *et al.* (1985).

TABLE 4

Regression Results of MV Adoption, Fertiliser Demand and Rice Cropping Intensity Function[a]

	MV	Log fertiliser		Rice cropping intensity	
	(1)	(2)	(3)	(4)	(5)
IRG	67·7**	1·14**	0·16	96·7**	79·1**
	(3·30)	(3·26)	(0·70)	(6·15)	(7·69)
FAV	71·6**	1·05**	–	18·5	–
	(3·12)	(3·19)		(1·25)	
DPRONE	−29·5	−0·75	–	−3·8	–
	(−1·26)	(−1·72)		(−0·19)	
MVR	–	–	1·68**	–	23·2
			(5·36)		(1·65)
UREAP[b]	6·5	−0·93	−1·21*	−14·6	−14·1
	(0·20)	(−1·43)	(−2·10)	(−0·51)	(−0·55)
FSIZE[b]	−1·8	0·18	0·22	−3·8	−3·5
	(−0·28)	(1·12)	(1·35)	(−0·53)	(−0·49)
ST	10·5	0·41	0·31	16·4	13·1
	(0·42)	(0·96)	(0·75)	(0·84)	(0·71)
OWNER	16·8	0·76	0·40	−3·2	−6·1
	(0·62)	(1·69)	(1·00)	(−0·16)	(−0·36)
PANAY	−0·7	0·29	0·29	19·8*	20·1*
	(−0·05)	(1·09)	(1·11)	(1·70)	(1·75)
Intercept	35·6	4·52**	4·12**	129·9*	119·7*
	(0·56)	(3·58)	(3·33)	(2·35)	(2·20)
R^2	–	0·583	0·582	0·722	0·722
Log likelihood	−113·5	–	–	–	–
(Chi-square)	(75·6)	–	–	–	–

[a]Numbers in parentheses are *t*-statistics. **Significant at the 1 per cent level; *significant at the 5 per cent level.
[b]Logarithms are taken in equations (2) and (3).

neither farm size nor tenure significantly affected the adoption rate of MVs (Ruttan 1977; Barker and Herdt 1985). These findings suggest that MV adoption is scale-neutral and credit is not likely to be a major constraint in MV adoption. Even during the early stages of MV introduction, tenancy and smallness of farm size ordinarily associated with low income levels did not seriously impede the adoption of modern varieties (Mangahas 1970; Liao 1968).

In the reduced-form fertiliser demand regression [equation (2)], two of the environmental variables (*IRG* and *FAV*) are highly significant. Moreover, fertiliser application in irrigated areas is not significantly higher than in favourable rainfed areas during the wet season since the difference in estimated coefficients is not significantly different. Indeed, equation (3) indicates that MV adoption is the most significant variable accounting for intervillage differences in fertiliser use and irrigation does not have any significant additional effect. It is remarkable to find that when the *MVR* is included the coefficient of *UREAP* has the expected sign and is significantly different from zero in equation (3), despite the relatively small interregional variation in the price ratio of fertiliser to paddy. As in the MV adoption function, farm size and tenure are not significant, implying that, at least in the long-run equilibrium, imperfections in credit markets do not significantly affect farmers' demand for fertiliser.

According to equation (4), rice cropping intensity in irrigated areas is higher than in unfavourable areas by about 100 per cent. There is, however, no indication that a favourable rainfed condition is conducive to higher rice cropping intensity which suggests that the introduction of MVs in favourable rainfed areas does not generally increase rice cropping intensity. In fact, the contribution of MVs to the rice cropping intensity while positive is found to be limited according to equation (5). However, in Panay Island where rainfall distribution is more even, the higher cropping intensity is indicated by the positive and significant coefficients of the regional dummy in both equations (4) and (5), and most likely it partially reflects the impact of shorter growth duration MVs.

Labour-saving technology

Table 5 presents the regression results of adoption functions of tractors, threshers and direct seeding. While land preparation wage (*LPW*), threshing wage (*THRW*), transplanting wage (*TPW*) and herbicide price (*HERBP*), deflated by paddy price, are included in the regressions, the actual rental cost of machines and draft animals is not

TABLE 5

Regression Results of Tractor, Thresher and Direct Seeding Adoption Functions[a]

	Tractor		Thresher		Direct seeding	
	(1)	(2)	(3)	(4)	(5)	(6)
IRG	84·6**	–	11·17	–	17·8	–
	(2·63)		(0·16)		(0·98)	
FAV	46·7	–	−11·89	–	21·5	–
	(1·54)		(−0·24)		(1·15)	
DPRONE	25·0	–	−80·20	–	−13·5	–
	(0·80)		(−1·40)		(−0·53)	
MVR	–	18·6	–	41·8	–	35·3*
		(1·25)		(0·81)		(1·76)
RCI	–	34·2**	–	30·7	–	−3·2
		(2·72)		(0·59)		(−0·22)
LPW	1·74	1·08	–	—	–	–
	(0·67)	(0·80)				
DIST	−0·16**	−0·10**	−0·02	−0·12	–	–
	(−2·98)	(−3·26)	(−0·18)	(−1·08)		
THRW	–	–	30·28*	14·67	–	
			(1·90)	(0·82)		
TPW	–	–		–	1·73	2·09
					(0·43)	(0·53)
HERBP	–	–	–	–	−4·76*	−4·71*
					(−2·00)	(−2·06)
FSIZE	38·5**	27·9**	16·44	15·8	3·70	4·83
	(3·02)	(4·08)	(0·88)	(0·77)	(0·27)	(0·37)
ST	9·7	8·7	−17·61	2·3	−16·2	19·1
	(0·33)	(0·50)	(−0·32)	(0·04)	(−0·62)	(−0·79)
OWNER	1·2	11·4	−14·12	−41·1	14·7	6·6
	(0·04)	(0·70)	(−0·25)	(−0·74)	(0·50)	(0·25)
PANAY	30·2	12·5	44·18	60·0	50·7**	51·5**
	(1·43)	(0·96)	(0·82)	(1·25)	(2·53)	(2·59)
Intercept	−29·8	−45·2	67·85	33·0	383·7	358·5*
	(−0·55)	(−1·58)	(1·09)	(0·42)	(1·77)	(1·69)
Log likelihood	−163·7	−164·9	−93·24	−94·3	−174·7	−174·8
(Chi-square)	(51·4)	(50·5)	(30·86)	(22·8)	(45·5)	(45·4)

[a]Numbers in parentheses are t-statistics. **Significant at the 1 per cent level; *significant at the 5 per cent level.

specified directly because of data limitations.[9] Instead, *RCI* was used to measure the rental cost of draft animals and the machine utilisation rate and distance from Manila (*DIST*) as a proxy for price and maintenance costs of machinery, since Manila is an industrial centre for the supply of agricultural machinery.

Not surprisingly, the estimation results of the tractor and direct seeding adoption functions are more satisfactory than those for threshers in terms of the significance of the estimated coefficients. Due to the very high adoption rates of threshers in the total sample villages (95 per cent), the factors affecting adoption of threshers are not very effectively analysed in our data set. Nonetheless, it is interesting to note that threshing wage has the expected positive and significant coefficient in equation (3). It is also clear that determinants of adoption for three technologies are markedly different.

While irrigation significantly affects only tractor adoption [equation (1)], MVs appear to affect only the use of the direct seeding method [equation (6)]. The positive and significant coefficient of irrigation in the tractor regression is consistent with our hypothesis that tractors will be adopted where the rental cost of draft animals is higher relative to tractors due to the limited area available for grazing draft animals. This interpretation is reinforced by the positive and significant coefficient of the *RCI* variable in equation (2). Adoption of MVs does not increase the adoption of tractors or threshers as evidenced by the insignificant coefficient of *MVR*. This suggests that wider adoption of tractors coincided with the spread of MVs because both are positively influenced by irrigation but for different reasons.

The positive and significant coefficient of MV adoption in the direct seeding regression [equation (6)] may be explained by the excellent seedling vigour and good tillering capacity of early-maturing MVs. The fact that none of the variables indicating degree of water control in equation (5) is significant suggests that different measures of the degree of water control are needed to determine the effect of environmental variables, such as the ease of drainage. The importance of environmental factors in the adoption of direct seeding is suggested by the significant coefficient of the Panay Island dummy which represents the condition of relatively even rainfall in this island.

An important finding in both equations (5) and (6) is the negative and significant effect of herbicide–paddy price ratio. Although this explains cross-sectional variation of direct seeding adoption, improvements in herbicide technology which lowered the effective cost of herbicides in the early 1970s must have been a major reason for the increase in adoption of direct seeding over time. The coefficient of the ratio of wages to paddy price is not significant in the adoption functions of all the labour-saving technologies due to the lack of significant regional wage variations. Nevertheless, the possibility cannot be denied that the rising trend in wages relative to the effective

[9] The data were not available in some villages where no rental market of machines existed. Even in the villages where contract hiring existed, the rental value of tractors differed markedly according to the number of passes and conditions of the soil. Rental cost of draft animals in a number of fully irrigated villages pertained to 'dukit', a specialised task of plowing sides of paddy fields and not to the ordinary task of land preparation.

price of herbicides could account for the spread of direct seeding in view of its significant labour-saving effect.[10]

Farm size is found to be significant in the adoption of tractors but not of threshers or direct seeding which suggests that economies of scale exists only in tractor technology. Such scale advantages do not lie on the favourable access of larger farmers to cheap credit because contract hiring of machines, which lessens the scale advantage of lumpy inputs, is much more common than individual ownership both in tractor and thresher operations. The insignificant coefficients of tenure variables also indicate that credit rationing in favour of wealthier farmers does not affect the adoption of labour-saving technologies in our sample villages. The major reason for the economies of scale in tractor use should be sought in the saving of the supervision cost of land preparation. Unlike land preparation by tractors, ploughing and harrowing with draft animals require care and judgement, which are not amenable to easy supervision, so that larger farmers tend to incur higher supervision costs (Otsuka, Chuma and Hayami 1989). It is likely that such a high enforcement cost induced large farmers to use tractors which standardise the farm task to reduce the cost of work monitoring.

Summary and Conclusions

In this paper, we examined long-run adoption behaviour of several major innovations in the Philippine rice sector in a unified analytical framework. We focused on the degree of complementarity between adoption rates of MVs *vis-à-vis* fertilisr use, cropping intensity and the adoption of labour-saving technologies. Cross-sectional differences in the adoption of MVs are explained mainly by environmental rather than socioeconomic factors. While irrigation was an important determinant of MV–fertiliser adoption in the early green revolution period, MV adoption, as well as fertiliser technology, is now equally desirable in the favourable rainfed conditions. Greater resistance to various pests, better tolerance to less favourable production conditions, shorter growth duration, and other improvements in the 'second' generation MVs undoubtedly have promoted the adoption of MVs under widely different conditions. It should be emphasised that environmental factors affect fertiliser use mainly through its impact on MV adoption. The ratio of fertiliser to paddy price also explains intervillage differences in fertiliser use, but there is no evidence that credit rationing limited fertiliser use of smaller and tenanted farms.

Despite the cross-sectional nature of the data set, it is clear that relative factor prices are important determinants of the adoption of labour-saving technologies. No indication was found that MVs directly induced adoption of tractors and threshers. MVs, however, may have indirectly promoted tractorisation by raising the profitability of irrigation investments which is the most decisive factor inducing higher cropping intensity (Hayami, David, Flores and Kikuchi 1976). With double cropping in irrigated areas, labour use per hectare per year will increase even though tractors are adopted. Evidently, adoption of direct seeding is associated with MV adoption. While in certain regions

[10] According to Cordova, Otsuka and Gascon (1988), the replacement of transplanting by direct seeding reduces labour for crop establishment by as much as 80 per cent.

MV adoption together with direct seeding have increased cropping intensity, in many other cases, MVs have indirectly reduced the labour demand by facilitating direct seeding.

Our analysis indicates that concern for the equity impact of technological change in rice production must consider not only the nature of MV–fertiliser technology, such as its location specificity, but also the importance of factor prices in affecting the farmer's decisions to adopt labour-saving technologies. Government policies that artificially reduce the cost of machinery and herbicides through overvaluation of the domestic currency and credit subsidy programmes are expected to promote technologies inconsistent with the country's resource endowments and, more seriously, are detrimental to the welfare of poor farmers and the landless whose livelihood critically depends on the labour employment opportunities.

References

Barker, R. and Cordova, V. G. (1978), 'Labor utilization in rice production' in *Economic Consequences of New Rice Technology*, International Rice Research Institute, Los Baños, Philippines.

—— and Herdt, R. W. (1985), *The Rice Economy of Asia*, Resources for the Future, Washington, D.C.

Barlow, C., Jayasuriya, S. and Price, E. C. (1983), *Evaluating Technology for New Farming Systems: Case Studies from Philippine Rice Farms*, International Rice Institute, Los Baños, Philippines.

Bhalla, S. S. (1979), 'Farm and technical changes in Indian agriculture' in R. Berry and W. Cline (eds), *Agrarian Structure and Productivity in Developing Countries*, Johns Hopkins University Press, Baltimore.

Binswanger, H. P. (1978), *The Economics of Tractors in South Asia*, Agricultural Development Council, New York.

Cordova, V. G., Otsuka, K. and Gascon, F. (1988), 'Technological change and labor use in rice farming', Agricultural Economics Department Paper No. 88-05, International Rice Research Institute, Los Baños, Philippines.

Coxhead, I. A. (1984), 'The economics of wet seeding: inducements to and consequences of some recent changes in Philippine rice cultivation', M.A. thesis, Australian National University.

Day, R. H. and Singh, I. (1977), *Economic Development as an Adaptive Process: The Green Revolution in Indian Punjab*, Cambridge University Press, Cambridge.

De Datta, S. K. (1980), 'Weed control in rice in South and Southeast Asia', *Food and Fertilizer Technology Centre Extension Bulletin*, Taipei, Taiwan.

Duff, B. (1978), 'Mechanization and use of modern rice varieties' in *Economic Consequences of New Rice Technology*, International Rice Research Institute, Los Baños, Philippines.

Falcon, W. P. (1977), 'The green revolution: generations of problems', *American Journal of Agricultural Economics* 59, 698–709.

Feder, G., Just, R. E. and Zilberman, D. (1985), 'Adoption of agricultural innovations in developing countries: a survey', *Economic Development and Cultural Change* 33, 255–98.

Frankel, F. R. (1971), *India's Green Revolution: Economic Gains and Political Costs*, Princeton University Press, NJ.

Garrity, D. P., Oldeman, L. R., Morris, R. A. and Lenke, D. (1986), 'Rainfed lowland rice ecosystems: characterization and distribution' in *Progress in Rainfed Lowland Rice*, International Rice Research Institute, Los Baños, Philippines.

Griliches, Z. (1957), 'Hybrid corn: an exploration in the economics of technological change', *Econometrica* 25, 501–22.

Hayami, Y., David, C. C., Flores, P. and Kikuchi, M. (1976), 'Agricultural growth against a land resource constraint: The Philippine experience', *Australian Journal of Agricultural Economics* 20(3), 144–59.

—— and Kikuchi, M. (1982), *Asian Village Economy at the Crossroads*, Johns Hopkins University Press, Baltimore.

Herdt, R. (1987), 'A retrospective view of technological and other changes in Philippine rice farming, 1965–1982', *Economic Development and Cultural Change* 35(2), 329–49.

Imperial, E. M. (1980), 'Chemical weed control in direct seeded rice (*Oryza sativa* L.) grown under puddled conditions', *Philippine Journal of Weed Science* 7, 70–5.

Jayasuriya, S. K. and Shand, R. T. (1985), 'Technical change and labor absorption in Asian agriculture', *World Development* 14, 415–28.

Judge, G. G., Griffith, W. E., Hill, R. C., Lutkepohl, H. and Lee, T. C. (1985), *The Theory and Practice of Econometrics*, 2nd edn, John Wiley and Sons, New York.

Liao, S. H. (1968), 'Factors affecting productivity and adoption of improved farm practices in rice farms', M.S. thesis, University of the Philipines, Los Baños, Philippines.

Lipton, M. P. with Longhurst, R. (1989), *New Seeds and Poor People,* Unwin Hyman, London.

Mangahas, M. (1970), 'An economic analysis of diffusion of new rice varieties in Central Luzon', Ph.D. thesis, University of Chicago.

Moody, K. (1982), 'Weed control in sequential cropping in rainfed lowland rice growing areas in tropical Asia' in M. Soejono, D. E. Binnes and T. O. Robson (eds), *Weed Control in Small Farms*, Bogor, Indonesia.

Otsuka, K. (1989), 'Determinants and consequences of land reform implementation in the Philippines', International Rice Research Institute, Los Baños, Philippines (mimeograph).

—— and Hayami, Y. (1988), 'Theories of share tenancy: A critical survey', *Economic Development and Cultural Change* 37(1), 31–68.

——, Chuma, H. and Hayami, Y. (1989), 'Toward a general theory of land and labor contracts in agrarian economies', International Rice Research Institute, Los Baños, Philippines (mimeograph).

——, Cordova, V. G. and David, C. C. (1989), 'Modern rice technology and regional wage differential in the Philippines', *Agricultural Economics*, forthcoming.

Rosett, R. N. and Nelson, F. O. (1975), 'Estimation of the two-limit probit regression model', *Econometrica* 43, 141–6.

Ruttan, V. W. (1977), 'The green revolution: seven generalizations', *International Development Review* 19, 16–23.

Schultz, T. W. (1975), 'The value of the ability to deal with disequilibrium', *Journal of Economic Literature* 13, 827–46.