The Developing Economies, XLIV-2 (June 2006): 167–89

THE IMPACT OF GREEN REVOLUTION ON RICE PRODUCTION IN VIETNAM

TRAN Thi Ut[1] and Kei KAJISA[2]

[1]*Center for Research Development and Technology Transfer, Binh Duong University, Vietnam; and* [2]*Foundation for Advanced Studies on International Development and National Graduate Research Institute for Policy Studies, Tokyo, Japan*

First version received June 2005; final version accepted December 2005

The current paper reviewed the development of the Green Revolution in Vietnam, using long-term regional yield and modern variety adoption statistics, as well as household data collected in 1996 and 2003. The present study indicates that the Green Revolution began in irrigated favorable areas and spread to the less favorable areas in Vietnam such as in other Asian countries. What is unique in Vietnam is that although the Green Revolution ended in the mid-1980s in the Philippines and Indonesia, it has still been sustained as of 2003. Our analyses revealed that such growth had been supported by continuous improvements of modern varieties by regional research institutes. The varieties imported from China have contributed to the Green Revolution in northern Vietnam and those developed by the International Rice Research Institute in southern Vietnam. The national agricultural research systems have also played a critically important role in developing location-specific and appropriate technologies.

Keywords: Green Revolution; National agricultural research systems; Modern varieties; Factor shares; Vietnam
JEL classification: Q16, O13, O33

I. INTRODUCTION

Unlike other Southeast Asian countries, rice production in Vietnam had been largely stagnant in the 1960s and increased only slightly in the 1970s. Neither significant area expansion nor yield growth took place in these earlier periods. This does not imply, however, that the Green Revolution in rice was not launched; it began, but was seriously interrupted by the Vietnam War. In contrast, the

The authors would like to thank the International Rice Research Institute and Foundation for Advanced Studies on International Development (FASID) for their financial supports in conducting this research. We are also indebted to useful comments and suggestions from Keijiro Otsuka as well as from the participants of the workshop on the "Green Revolution in Asia and Its Transferability to Africa" supported by FASID held in Durban, South Africa, August 13–16, 2003.

doi: 10.1111/j.1746-1049.2006.00012.x

growth rates of rice production in the 1980s and 1990s were truly remarkable, surpassing growth rates of rice production in all other Asian countries by wide margins. Although rice production increased at an annual average growth rate of 5%, rice yield and harvested areas increased at 3.5% and 1.5%, respectively, from 1980 to 2000. Such rapid expansion of rice production made it possible for Vietnam to be a major rice exporter since 1989, exporting 1.7 million tons in 1989 and as much as 3.6 million tons in 2000.

A major question is how Vietnam has achieved such a high growth performance in rice production for the last two decades. Undoubtedly, the Doi Moi policy, which was initiated in 1986 and aimed to reform the economic system towards a market-oriented economy, contributed to the expansion of rice production by improving the efficiency of marketing sectors and strengthening individual land use rights and farm management autonomy (IFPRI 1996; Irvin 1995; Pingali and Vo-Tong 1992). No less important would be the introduction of modern rice technology, particularly fertilizer-responsive, high-yielding modern rice varieties (MV). The MV adoption rate was only 17% in 1980 but increased to nearly 90% as of 2000. Yields of MV grew significantly from 2.0 to 2.5 tons per hectare in 1980 to 3.0 to 5.5 tons in 2002, depending on different ecological regions of the country.

The purposes of the present paper are twofold. First, using pooled regional data from 1980 to 2002, we show the trend of the increasing MV adoption and of the increasing yield effects over time. We also show that as in the case of other Asian countries, the yield effects of MV were particularly pronounced in the favorable conditions, especially during the dry season cultivation under irrigation. Second, using household-level data collected in 1996 and 2003, detailed characterization of Vietnam's Green Revolution was carried out. More specifically, we show that even after the completion of MV adoption over traditional varieties (TV), the replacement of old MV with new MV kept the momentum of Vietnam's Green Revolution going. Our micro-level analysis examines who adopts these new MV and what the impact on rice yield is. We also consider how important it is for a country such as Vietnam, where agroecological conditions is diversified from north to south, to continuously release location-specific MV through the importation from the countries with similar agroecological conditions or through the research by national agricultural research systems (NARS).

The organization of this paper is as follows. We describe the process of MV adoption and changing differences in yields between MV and TV by major regions in Vietnam, together with institutional and agroecological backgrounds behind these differences, in Section II. In Section III, we estimate a yield function using the pooled regional data. In Section IV, we present the characteristics of sample villages and households surveyed in 1996 and 2003, which will be followed by the estimation of MV adoption and rice yield functions, and a factor share analysis. Section V concludes the paper by drawing policy implications.

II. MODERN VARIETIES ADOPTION AND YIELD CHANGES IN VIETNAM

High-yielding modern rice variety, IR8, was first introduced into South Vietnam in May 1966 by Long Dinh Rice Research Station located in My Tho Province (Tien Giang Province in the present time). Its average yield was 4 tons per hectare, which far outweighed the yield of traditional varieties of 2 tons per hectare (Tran 2001). For a wider diffusion, IR8 was renamed to Than Nong 8 (TN8), which stands for "miracle rice" in Vietnamese. Since then, the area under MV expanded rapidly throughout the southern region. The MV adoption rate increased from 1.0% in 1968 to 33% in 1975. Total rice-planted area also increased importantly because of the introduction of non-photoperiod sensitive, short-maturing MV, which facilitated double-cropping of rice.

In northern Vietnam, too, IR8 was introduced in 1968, which was renamed as NN8, in which NN (*nong nghiep*) means agriculture in Vietnamese (Tran, Hossain, and Janaiah 2000). Although systematic data are not available, it was reported by Vo-Tong (1995) that IR8 was well adapted to the winter–spring crop of 1968–69 and soon covered about 50% of the rice area in the early 1970s in North Vietnam.

Although IR8, as well as IR5, was adopted widely in the early process of the Green Revolution in Vietnam, these first-generation MV were seriously affected by an outbreak of brown plant hopper (BPH) in 1972 in South Vietnam. Thus, they were replaced with TN73-1 and TN73-2 (formerly known as IR1529-6-80 and IR1561-22-8) and a series of new International Rice Research Institute (IRRI) varieties such as IR26 and IR30, which were more resistant to the BPH biotype1. Yet, nearly 700,000 hectares of rice areas planted to MV in the Mekong River Delta were damaged by BPH and ragged stunt disease in 1978. Thereafter, IR36, which is characterized by stronger resistance to the new BPH, other pests, and diseases, was rapidly introduced, particularly in pest-prone and disease-prone irrigated rice areas (Vo-Tong 1995). Regardless of this rapid replacement with superior MV, however, as a result of the Vietnam War before 1975, the rice-harvested area and production had unduly stagnated until the early 1980s (Figure 1).

In contrast, the growth of rice production in the 1980s and 1990s was truly remarkable. During this period, rice production increased at a much faster rate than harvested area, indicating that the improvement of land productivity was a major source of production increase (Figure 1). The trend of rice yield in Figure 2 confirms this point; the average rice yield over the seasons had increased from 2.2 to 4.4 tons per hectare in the 20 years. Moreover, it can be shown that the increase in rice yield was associated with the rapid spread of MV (Figure 3), the increase in irrigated area (Figure 4), and chemical fertilizer application (Figure 5), which is the feature of Green Revolution observed also in other Asian tropics. Another typical feature observed is that the increase in average yield was attributed largely to the improvement in dry season (winter–spring season) rice yield (Figure 2). Note that the winter–spring

Fig. 1. Rice Production and Harvested Area from 1960 to 2003 (log scale)

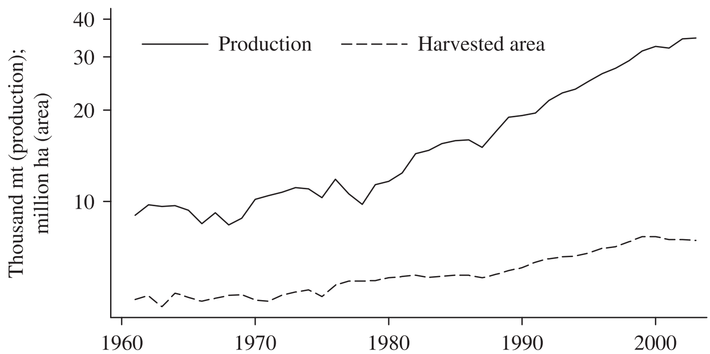
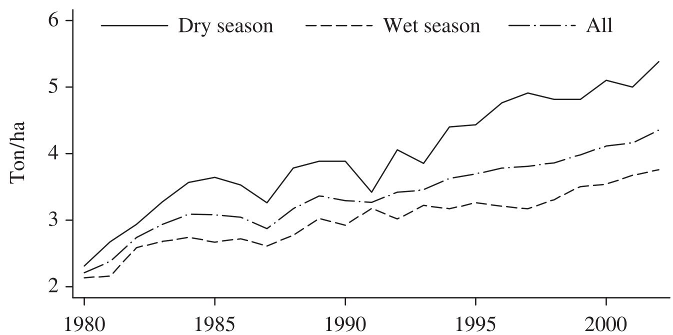


Fig. 2. Rice Yield at Different Seasons from 1980 to 2002



season rice is grown almost exclusively under irrigated conditions with longer sunshine exposure, whereas the rice during other seasons (summer and summer–fall) is grown under both irrigated and rainfed conditions. The yield of the latter two seasons, which we can call the wet season, had been increasing at a slower rate, resulting in widened yield gap between the two seasons over time.

It is important to observe that the rice yield continued to increase in the 1980s and even in the 1990s (Figure 2), unlike the case of the Philippines, which experienced stagnated yield growth since the mid-1980s (Estudillo and Otsuka 2006). The increase of yield has continued even after the replacement from TV to MV has almost reached its plateau in the late 1990s (Figure 3), implying that the continuous release of newer MV and switching to them had kept the momentum of Vietnam's Green Revolution going. In the early 1980s, several varieties resistant to BPH were released. Furthermore, Can Tho University developed a new series of MV with good grain quality and strong resistance to the new BPH from 300 line crosses with cultivars containing

Fig. 3. Modern Rice Varieties Adoption Rate at Different Seasons from 1980 to 2002

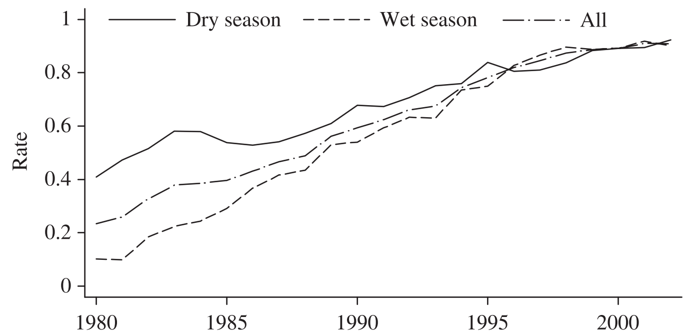
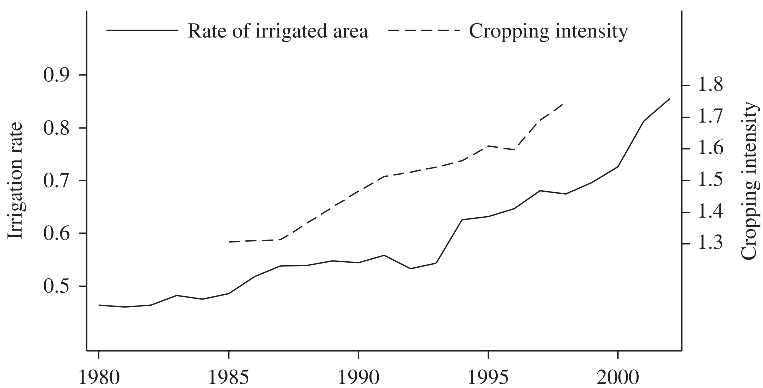


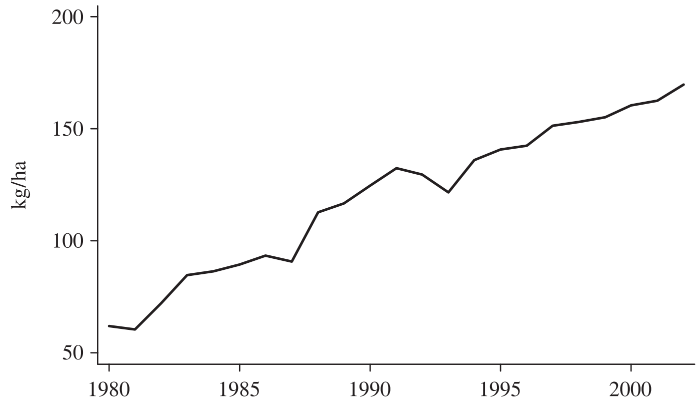
Fig. 4. Rate of Irrigated Area and Cropping Intensity from 1980 to 2002



the BPH-resistance gene sent from the IRRI. In saline-affected rainfed rice fields with semi-deep water, which prevails in the Mekong River Delta, IR42 showed great suitability and virtually replaced the traditional medium-height rice varieties. This variety was grown in more than 400,000 hectares in the southern part of Vietnam (Vo-Tong 1995). In addition, most varieties transferred from IRRI in the 1980s were highly resistant to blast, particularly IR1820-210-2 and CR203, which were widely planted for the blast prone areas in northern Vietnam. These new improved varieties can be called second-generation MV (MV2), following Estudillo and Otsuka (2006).

During the 1990s, dozens of 80-to-90-day varieties classified as MV3 were released from Cuu Long Delta Rice Research Institute (CLRRI). In these varieties, the variety *Omon Chin Som* (OMCS2000), was grown on 60 hectares in 2001. The latest variety OMCS21 achieves higher yield (7 tons per hectare) and more resistance to BPH and rice blast with shorter duration (80 days), and thus it is suitable for cultivation in flood prone areas such as the Mekong Delta. In addition, the Southern

Fig. 5. Fertilizer Application per Hectare from 1980 to 2002



Agricultural Sciences Institute developed varieties VND95 in 1995 and VND96 in 2000, which were planted in large areas in the Mekong region. In northern Vietnam also, Agricultural Science Institutes have developed a series of MV3 such as C70 and C71 from the Plant Protection Institute (PPI), Di Truyen (DT)10 and DT11 from the Agricultural Genetic Institute (AGI), and X23 from the Vietnam Agriculture Science Institute (VASI). These varieties were planted in large areas in North Vietnam that we find in our case study to be discussed in Section IV. Reflecting the release and subsequent adoption of MV2 and MV3, rice yields steadily increased in the 1980s and also in the 1990s.

Another reason for continuous yield increase seems to lie in the rapid expansion of the irrigated area since the mid-1990s (Figure 4). This expansion increased the area of dry season cultivation remarkably, resulting in the increase in the crop intensity and the average yield.

The macro-level story mentioned above masks regional variations. In Vietnam, because of the diversity of ecological conditions, suitable MV and accordingly their dissemination processes vary considerably in each of the seven major rice-growing regions, which are North Mountain Highlands (NMH), Red River Delta (RRD), North Central Coast (NCC), South Central Coast (SCC), Central Highlands (CH), North East South (NES), and Mekong River Delta (MRD) (Figure 6).[1] The most favorable rice-growing region is RRD, owing to the stability of the Red River Dyke and irrigation system. Table 1 shows that the rate of irrigated area in this region was already 75% in 1980 and had been the highest for the entire period. The region of

[1] Note that ecological regions in Vietnam are divided now into eight regions in which NMH is divided by two regions: North East and North West. However, for comparability with the existing works, we still use the former definition.

Fig. 6. Seven Agroecological Regions of Vietnam

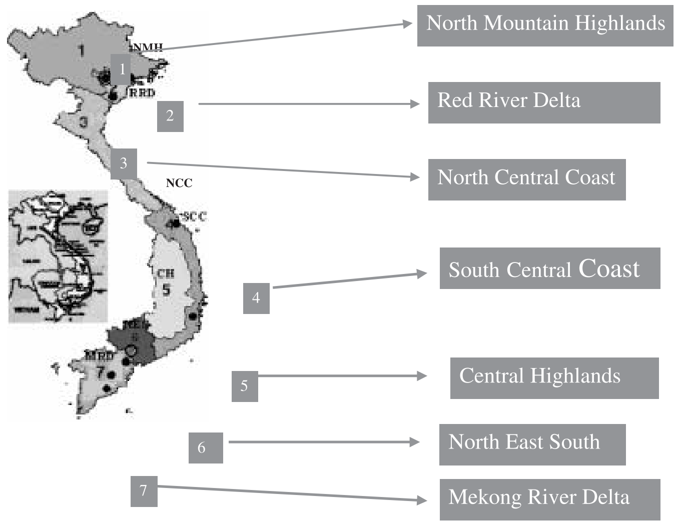


TABLE 1

Changes in Irrigated Rice Area by Major Ecological Region in Selected Years from 1980 to 2002

(%)

	Rate of Irrigated Area							
	Whole Country	NMH	RRD	NCC	SCC	CH	NES	MRD
1980	46	50	75	53	31	10	9	41
1985	49	49	73	53	37	13	14	46
1990	55	55	80	60	48	18	20	52
1995	64	58	89	71	52	22	27	64
1998	68	59	91	76	64	30	36	67
2002	85	57	100	80	88	41	69	91

Source: General Statistical Office, Vietnam.
NMH = North Mountain Highlands; RRD = Red River Delta; NCC = North Central Coast; SCC = South Central Coast; CH = Central Highlands; NES = North East South; MRD = Mekong River Delta.

NES is also regarded as a favorable place for rice cultivation. However, this region has advantages in perennial crops, and thus attention has not been paid to irrigation facilities for rice, resulting in moderate growth of irrigation rate in Table 1. Other regions such as NCC, SCC, and MRD caught up with RRD quickly in terms of irrigation rates. Among them, the improvement of MRD's agronomic condition was

TABLE 2

Changes in Total Rice Area and Modern Varieties Adoption by Major Ecological Region in Selected Years from 1980 to 2002

	Total Rice Area (1,000 ha)	Adoption Rate of MV (%)							
		Average	NMH	RRD	NCC	SCC	CH	NES	MRD
1980	5,543	16.9	4.7	52.9	10.1	17.3	2.3	9.3	9.7
1985	5,703	28.5	6.4	68.4	11.8	23.0	9.8	16.3	26.4
1990	6,028	47.5	30.8	78.5	17.6	47.6	44.3	41.3	48.3
1995	6,766	76.2	63.8	90.5	62.0	60.8	75.2	79.7	79.8
1998	7,362	87.2	81.2	92.2	87.1	81.9	83.0	91.3	87.7
2002	7,463	94.2	84.5	96.3	87.1	88.2	77.2	87.6	99.5

Source: General Statistical Office, Vietnam.
NMH = North Mountain Highlands; RRD = Red River Delta; NCC = North Central Coast; SCC = South Central Coast; CH = Central Highlands; NES = North East South; MRD = Mekong River Delta; MV = modern rice varieties.

remarkable. Before the construction of canals in 1983, many parts of this region were unfavorable rainfed areas and cultivated floating rice. After the construction, the delta area of this region turned to an irrigated and intensive ecosystem and it is now considered as favorable as RRD. Note, however, that the outer MRD region is still flood-prone unfavorable area. The other catching-up regions, i.e., NCC and SCC are still considered as less favorable regions. Moreover, mountainous regions such as NMH and CH have significant geographical difficulty in increasing irrigated area, being considered as least suitable area for rice cultivation.

The RRD, the most favorable region with the highest irrigation rate, shows also the highest rate of MV adoption which already exceeded 50% in 1980, far exceeding all other regions (see Table 2). Moreover, the yield of MV was the highest in this region (Table 3). However, other regions caught up with RRD in the MV adoption in subsequent years. For example, MRD, which is the rice bowl of Vietnam, accounting for 44% of total rice area and 48% of the overall rice production in the 1980s, rapidly expanded the MV adoption area. Although other regions are less favorable than the two delta regions, the rate of MV adoption increased significantly in the last two decades. Among them, the rapid adoption in less and least unfavorable regions (NMH, CH, NCC, and SCC) is attributed partly to the fact that subsidies from government on seeds and fertilizers to the farmers in coastal areas, islands, or mountainous areas have encouraged their adoption.

It is widely recognized that rice research systems in Vietnam have been designed to develop rice varieties appropriate for the diverse production environments in the country. In addition to national-level research institutes, Vietnam has very strong regional institutes such as VASI (Northern), Southern Agricultural Science Institute (SASI), and Mekong River Delta Rice Research Institute. Agricultural universities also have contributed to the development of location-specific technologies with the

TABLE 3

Yields of Modern Varieties and Traditional Varieties by Major Ecological Region in Selected Years from 1980 to 2002

(t/ha)

	MV							TV						
	NMH	RRD	NCC	SCC	CH	NES	MRD	NMH	RRD	NCC	SCC	CH	NES	MRD
1980	2.1	2.6	1.6	2.4	2.3	2.2	2.5	1.3	2.0	1.3	2.2	1.6	2.0	2.3
1985	2.6	3.2	2.4	3.4	2.4	2.7	2.9	2.1	2.3	2.1	3.2	2.2	2.6	3.1
1990	2.9	3.8	2.6	3.5	2.8	2.8	4.0	2.4	2.1	2.4	3.0	1.9	2.4	3.4
1995	3.1	4.7	3.2	3.8	2.8	2.8	4.2	3.0	2.0	3.0	2.8	1.5	2.1	3.3
1998	3.4	5.3	3.7	3.7	3.0	3.0	4.3	2.5	3.1	2.5	2.5	0.9	1.5	2.8
2002	4.4	5.7	4.8	4.3	3.5	3.4	4.5	3.0	3.2	2.6	3.2	2.3	2.2	3.3

Source: General Statistical Office, Vietnam.
NMH = North Mountain Highlands; RRD = Red River Delta; NCC = North Central Coast; SCC = South Central Coast; CH = Central Highlands; NES = North East South; MRD = Mekong River Delta; MV = modern rice varieties; TV = traditional varieties.

collaboration with public research institutes. A good example is the effort to shorten the growth duration to avoid flooding at harvest time in the summer–fall growing season in the MRD region by developing OM1490 and OMCS96 with super early ripening of 85–90 days from sowing to harvest. Another example is the development of Tep Hanh Dot Bien (THDB) (mutant from TV) with salinity tolerance for cultivation in brackish areas, in order to rotate with shrimp production with early (105–15 days) and medium (125–45 days) ripening (Bui 2000). In addition, the scientists developed MV with resistance to pests and diseases, particularly useful for irrigated areas, and those with tolerance of salinity and acid sulfate, particularly useful for rainfed areas in MRD (Pham and Bui 1999). Besides, a lot of Chinese MV were introduced and modified to local conditions in northern Vietnam especially in the areas located nearby the Vietnam–China border. In our study sites, several Chinese MV such as Khang Dan (MV3), Tap Giao (MV1), Doan Ket (MV1) were found in the NMH region. There is no question that the efforts of developing location-specific technologies at regional research institutes and universities have contributed to the continuous release of new MV in the 1990s.

Agricultural extension systems have played significant roles in the delivery of location-specific technologies to local farmers. District-level extension stations design extension programs and village-level extension agents transfer technologies to farmers with the help from local social organizations, such as youth groups, women's organizations, and farmers' clubs. Although all extension systems are managed under the Ministry of Agriculture and Rural Development, regional differences exist; because of weak relationships with research institutes and universities at unfavorable regions, the dissemination of technologies there has not proceeded as fast as that of favorable regions. It is important to observe that the regional differences in MV yields between favorable areas (e.g., RRD and MRD) and other less favorable areas have widened over the last two decades (Table 3), regardless of unfavorable regions' catching up in MV adoption rates.

III. REGRESSION ANALYSIS WITH POOLED REGIONAL DATA FROM 1980 TO 2002

In this section we estimate a yield function in order to systematically examine the characteristics of Vietnam's Green Revolution, using official regional data covering seven regions from 1980 to 2002. The dependent variable is $\ln(yield_{ijt})$, where subscripts refer to *i*th region, *j*th season, and *t*th year, respectively. We classify the seasons into dry (winter–spring) and wet (summer and summer–fall). The first explanatory variable we use is MV adoption rate (*mvrat*) whose coefficient measures the percentage yield advantage of MV over TV. Another explanatory variable is irrigation rate (*irrirat*), which is expected to affect the yields positively. Note, however, that since the dry season rice is grown exclusively under irrigated conditions, the irrigation rate matters only during the wet season; we introduce an interaction term between wet season dummy (*wet*) and *irrirat*, namely, *irrirat*∗*wet*. In this regard, the dry season dummy (*dry*) captures not only the impact of weather but also the impact of full irrigation. The coefficients of six regional dummies are expected to capture the regional differences in yields as a result of region-specific factors. As explained, region-specific factors include agroecological differences and existence of input subsidies from the government. Since the default area (RRD) is a favorable production area, we expect negative signs on the dummies. We also expect that the magnitude of the coefficients on the dummies for NMH, NCC, SCC, and CH becomes small if subsidies effectively reduce disadvantages of these regions. The coefficients of year dummies are expected to capture the effects of changing overall production environments in Vietnam, some of which would have been affected by the Doi Moi and other reform policies. Specifically, we would like to postulate that such policy impacts would have been pronounced particularly in the late 1980s and the early 1990s, as the major policy reforms were implemented in that period (Irvin 1995; IFPRI 1996). We use the model with these variables as our base (Model 1).

Other interesting characteristics to be examined are: (i) whether higher MV impact on yield was achieved under the dry season than the wet season environment; (ii) whether the impact of MV on yield had yet to be stagnated or even increased; and (iii) whether regional differences in yields were widened. For the first point, we generate an interaction term between *mvrat* and *dry*, namely, *mvrat*∗*dry*, expecting positive coefficient. To examine the latter two points, we generate interaction terms between a period dummy becoming one in and after 1988 (*aft88*) and some explanatory variables such as *mvrat*, *mvrat*∗*dry*, and regional dummies. In other words, we examine whether the structure of Vietnam's Green Revolution changed in 1988. The year 1988 is chosen because it is the year that Doi Moi (since 1986) was exemplified in rice sector as the policy of rice market liberalization (Young *et al.* 2002). The results with these additional interaction terms are shown as Model 2. As we will see in the household data analysis, the MV impact even increased during the period of 1996–2003. To examine whether this happened at macro-level, we introduced additional interaction terms with a period dummy becoming one in and after 1996 (*aft96*); *mvrat∗aft96* and *mvrat∗dry∗aft96*. The results of this functional specification are shown as Model 3.

Ordinary least squares (OLS) regression results are reported in Table 4. Since most of the newly added interaction terms are highly significant in Model 3, we use it for our discussion as the one which is least suffered from the omitted variable problem. The estimated coefficient of *mvrat* implies that rice yield increased 28% because of MV adoption even under rainfed conditions before 1988.[2] The impact increases to 72% with irrigation in wet season and to 110% in dry season. This supports our claim that adoption of MV increased the yield significantly and that MVs' potential was highly used under irrigated conditions especially in the dry season.

The other points discussed in the previous section are also statistically supported by the data. First, insignificant coefficients of *mvrat∗aft88* and *mvrat∗aft88∗dry* indicate that the impact of MV was not significantly reduced in Vietnam, even in the late 1980s and early 1990s. Moreover, as indicated by a positive and significant coefficient of *mvrat∗aft96∗dry*, it increased in the dry season after 1996 presumably because the adoption of superior MV occurred even in the late 1990s, resulting in continuous yield growth. This point will be more carefully examined with the household data. Second, regional dummies and its interaction terms with *aft88* show that regional disparities against RRD were unfavorably increased in NMH, NCC, SCC, CH, and NE, implying that the subsidies to unfavorable regions have not been effective in reducing the gap. These results suggest that the Green Revolution has been sustained in Vietnam owing to the continued research efforts to improve new technologies in such favorable rice-growing areas such as RRD and MRD.

Last, it is of interest to discuss policy impact using year dummies from 1981 to 2002. Letting all the year effect be captured in year dummies, Model 1 indicates that coefficients of year dummies are significant and the magnitudes are basically increasing over time in a stepwise manner. We observe the first jump in the late 1980s which support our claim that the Doi Moi and other reforms have significant impacts on rice yield. Free-market system under Doi Moi policy might have increased farmers' investment in rice field, resulting in higher productivity. The second jump around the late 1990s and early 2000s might be because of the contribution of several large irrigation systems in MRD for protecting saline water and for getting fresh

[2] The percentage impact is calculated from Table 4 as [exp(0.247) – 1]∗100. The same applies to the other percentage impact calculation.

TABLE 4

Ordinary Least Squares Result of ln (*Yield*) Regression, 1980–2002

	Model 1	Model 2	Model 3
mvrat	0.148	0.256	0.247
	(2.60)***	(2.17)**	(2.11)**
mvrat∗*aft88*		−0.191	−0.112
		(1.45)	(0.82)
mvrat∗*aft96*			−0.032
			(0.16)
mvrat∗*dry*		0.253	0.222
		(1.94)*	(1.70)*
mvrat∗*dry*∗*aft88*		0.024	−0.059
		(0.25)	(0.58)
mvrat∗*dry*∗*aft96*			0.140
			(2.28)**
irrirat∗*wet*	0.226	0.250	0.288
	(2.37)**	(2.49)**	(2.86)***
dry	0.409	0.234	0.276
	(6.72)***	(3.09)***	(3.56)***
nmh	−0.239	−0.026	−0.032
	(6.30)***	(0.33)	(0.42)
ncc	−0.308	−0.157	−0.163
	(8.29)***	(2.13)*	(2.22)**
scc	−0.170	0.008	0.006
	(4.20)***	(0.11)	(0.08)
ch	−0.187	−0.024	−0.024
	(4.49)***	(0.33)	(0.34)
nes	−0.284	−0.300	−0.286
	(6.86)***	(3.57)***	(3.42)***
mrd	0.061	0.222	0.227
	(1.85)	(3.73)***	(3.84)***
nmh∗*aft88*		−0.264	−0.239
		(2.97)***	(2.68)***
ncc∗*aft88*		−0.175	−0.157
		(2.07)**	(1.86)
scc∗*aft88*		−0.237	−0.210
		(2.73)***	(2.38)**
ch∗*aft88*		−0.224	−0.201
		(2.57)**	(2.30)*
nes∗*aft88*		−0.030	−0.019
		(0.31)	(0.20)
mrd∗*aft88*		−0.228	−0.226
		(3.24)***	(3.23)***
year 1981	0.094	0.080	0.082
	(1.47)	(1.29)	(1.33)
year 1982	0.226	0.202	0.205
	(3.52)***	(3.23)***	(3.30)***
year 1983	0.258	0.219	0.223
	(4.00)***	(3.45)***	(3.53)***
year 1984	0.341	0.297	0.301
	(5.27)***	(4.64)***	(4.74)***

TABLE 4 (Continued)

	Model 1	Model 2	Model 3
year 1985	0.340	0.297	0.301
	(5.26)***	(4.64)***	(4.73)***
year 1986	0.329	0.284	0.288
	(5.09)***	(4.41)***	(4.50)***
year 1987	0.285	0.232	0.237
	(4.39)***	(3.54)***	(3.64)***
year 1988	0.352	0.550	0.531
	(5.50)***	(5.62)***	(5.45)***
year 1989	0.394	0.589	0.570
	(6.11)***	(5.95)***	(5.77)***
year 1990	0.402	0.589	0.571
	(6.30)***	(5.94)***	(5.78)***
year 1991	0.346	0.536	0.515
	(5.38)***	(5.36)***	(5.16)***
year 1992	0.386	0.573	0.551
	(5.92)***	(5.64)***	(5.44)***
year 1993	0.457	0.641	0.618
	(7.07)***	(6.31)***	(6.10)***
year 1994	0.470	0.658	0.630
	(7.18)***	(6.38)***	(6.10)***
year 1995	0.474	0.658	0.630
	(7.14)***	(6.28)***	(6.01)***
year 1996	0.493	0.683	0.619
	(7.29)***	(6.39)***	(3.37)***
year 1997	0.535	0.727	0.661
	(7.85)***	(6.75)***	(3.52)***
year 1998	0.535	0.727	0.659
	(7.76)***	(6.68)***	(3.41)***
year 1999	0.607	0.796	0.728
	(8.86)***	(7.34)***	(3.80)***
year 2000	0.629	0.819	0.751
	(9.17)***	(7.54)***	(3.90)***
year 2001	0.709	0.885	0.809
	(9.73)***	(7.99)***	(4.15)***
year 2002	0.728	0.898	0.820
	(9.90)***	(8.03)***	(4.10)***
Constant	0.483	0.368	0.344
	(6.25)***	(3.99)***	(3.74)***
Observations	306	306	306
R-squared	0.78	0.80	0.81

Note: Absolute value of *t*-statistics in parentheses.
***, **, and * represent statistical significance at the 1%, 5%, and 10% level respectively.

water from Hau River. Also, recently the largest dams have started their operations in Ba Lai River, Ben Tre Province, MRD.[3] Besides, the creation of "Rice Export Zones" in several favorite areas in Dong Thap Province and Hau Giang Province in Mekong River Delta region also accelerated the rice production in this period.

IV. ANALYSIS OF HOUSEHOLD DATA IN 1996 AND IN 2003

A. *Characteristics of the Sample Villages and Households*

In this section, we explore Vietnam's Green Revolution using household data collected by the collaboration among Nong Lam University, Ho Chi Minh City (UAF, Vietnam), the IRRI (the Philippines), and the Foundation for Advance Studies for International Development (FASID, Japan) in 1996 and in 2003. To draw a representative sample from diverse ecological regions, eight villages from the four distinct agroecosystems are selected: one irrigated and one rainfed villages in highlands in the North Mountain Highlands, one irrigated and one rainfed villages from densely populated and generally irrigated lowlands in the RRD, two rainfed villages from lowlands in the outer region of MRD, and two irrigated villages from lowlands in the MRD. In conducting the survey, nearly 50 households in each village were randomly selected using a stratified random sampling method. A structured pretested questionnaire was used to interview the sample households to generate primary information on various aspects of the household economy. In total, 366 sample households in 1996 and 425 households in 2003 were drawn from eight villages.

Table 5 shows the changes in rice cultivations and socioeconomic characteristics of sample households by four agroecological regions from 1996 to 2003. The process of the Green Revolution shown by this table is basically consistent with the one shown by regional data. Overall, rice yield kept increasing in association with the increased irrigation and fertilizer application. Note that in this period the MV adoption was almost complete both in the dry and the wet seasons, except for the wet season in outer MRD.[4] This implies that in the late 1990s and the early 2000s, the major source of the growth was not the adoption of MV itself but because of switching from old MV to new MV. Note also that the results described above are shared across the four agroecological regions.

[3] This 600 m dam is one of the most important irrigation works in the MRD, across the Ba Lai River. This dam project aims to stop the infiltration of salt water and to preserve fresh water for 100,000 hectares of farmland in Ben Tre.

[4] We would like to remind again that high MV adoption rates in the dry season do not necessarily mean MV cultivation in the entire paddy fields; cultivable paddy land is limited in the dry season. The data show high adoption rate in NMH and in outer MRD, which are characterized by less favorable conditions. The cultivated area is much smaller than total area in the dry season in those two areas in 1996. In outer MRD, saline water problem made many farmers fallow their land. Limited access to irrigation facilities made NMH's cultivable area much smaller than total area in the dry season. Nevertheless, the farmers who could cultivate used MV in those areas, resulting in high adoption rate.

TABLE 5

Changes in Rice Cultivations and Socioeconomic Characteristics of Sample Households by Agroecological Region from 1996 to 2003

	All		North				South			
			NMH		RRD		MRD (Outer region)		MRD (Delta)	
	1996	2003	1996	2003	1996	2003	1996	2003	1996	2003
Yield (dry) (t/ha)	4.79	5.18	4.29	4.78	3.99	4.20	3.21	4.01	6.83	6.97
	(1.69)	(1.62)	(0.94)	(0.88)	(1.10)	(1.07)	(1.01)	(1.16)	(0.87)	(1.12)
Yield (wet) (t/ha)	3.48	4.09	3.81	4.60	3.01	3.88	2.85	2.95	4.36	4.78
	(1.24)	(1.41)	(0.77)	(0.90)	(1.54)	(1.16)	(1.09)	(1.65)	(0.66)	(1.06)
Irrigation ratio	0.51	0.61	0.54	0.63	0.50	0.53	0.00	0.00	1.0	1.0
MV adoption rate (dry) (%)	0.97	1.00	1.00	1.00	1.00	1.00	0.88	1.00	1.00	1.00
MV adoption rate (wet) (%)	0.90	0.90	1.00	1.00	1.00	1.00	0.49	0.37	0.97	1.00
Farm size (ha)	0.65	0.56	0.17	0.07	0.25	0.06	0.45	0.42	1.54	1.47
	(0.98)	0.82	(0.10)	(0.05)	(0.17)	0.04	(0.23)	(0.26)	(1.43)	(0.92)
Fertilizer use (N) (kg/ha)	96.3	125	83.2	162	149	137	30.3	82.9	117	105
	(65.1)	51.8	(67.7)	58.6	(47.8)	44.1	(40.6)	(42.5)	(23.8)	(28.3)
Working member	3.39	3.42	3.46	3.05	3.13	3.45	3.1	3.55	3.9	3.62
	(1.63)	1.58	(1.64)	1.47	(1.37)	1.31	(1.6)	(1.88)	(1.8)	(1.70)
Age of HH head	47.1	50.4	44.6	50.1	46.1	48.9	45.8	54.6	52.2	49.9
	(12.7)	13.0	(14.1)	15.3	(10.5)	11.3	(12.5)	(13.2)	(12.5)	(12.3)
Schooling years of HH head	5.93	6.37	5.53	6.03	6.6	6.92	5.6	6.51	5.8	6.05
	(2.92)	3.13	(2.71)	2.42	(2.4)	2.93	(3.4)	(3.49)	(3.0)	(3.58)
Ratio of Male HH head	0.75	0.85	0.67	0.82	0.66	0.86	0.71	0.80	0.94	0.88
No. of HH	366	425	88	103	100	97	92	102	86	123

MV = modern rice varieties; HH = household head; NMH = North Mountain Highlands; RRD = Red River Delta; MRD = Mekong River Delta.

Farm size shrunk especially in the regions in the North. In RRD, paddy fields were converted to vegetable farms or shrimp production which generates high returns. Furthermore, because of the urbanization, paddy fields were also converted to residential areas.

Age, schooling, and sex of household heads, as well as the number of working members between 15 and 60 years of age, are not so different across the regions during the period of 1996–2003; an exception is the sex of household heads in the North in 1996, where minority groups in highlands are subject to matrilineal inheritance system.

In Vietnam's context, the sex of household heads is not important either in the introduction of MV or in determining the yield mainly because the dissemination of the MV technology through the extension officials and national research institutes is sex-neutral. Unlike in some developing countries, experience of the Vietnam War had increased the number of female household heads, and such households became socially accepted without any sex discrimination. The household survey collected information on rice varieties grown by sample farmers to see the replacement process in MV and its impacts on yield. In our study rice varieties are classified into the following groups based on generations and origins.

TV:	Traditional varieties.[5]
MV1:	The varieties developed and released prior to 1970.[6]
MV2:	The varieties developed and released during the 1980s characterized by the traits of high yield and strong resistance to blast.[7]
MV3 (NARS-N):	The varieties with the traits of high yield, strong resistance to blast, and good grain quality, which were developed and released during the 1990s by NARS in northern region such as PPI, AGI, VASI.[8]
MV3 (China):	The hybrid varieties with the MV3 traits imported from China or originally imported from China and then multiplied by Quang Nam Seed Company in the central region.
MV3 (NARS-S):	The varieties with the MV3 traits developed by NARS in the South such as CLRRI, Cand Tho University, and SASI.[9]
MV3 (IRRI):	The varieties with the MV3 traits transferred from IRRI.[10]

[5] They include several local rice varieties such as Nho Do, Nang Thom, Tai Nguyen, etc.

[6] They include Bao Thai, Moc Tuyen, and Doan Ket which were developed in China prior to 1967.

[7] Examples are CR 203, U17, and Mashuri.

[8] The varieties from PPI are C70 and C71, those from AGI are DT10 and DT13, and that from VASI is CK95.

[9] The varieties from CLRRI are OMCS94, OMCS2000, and OM997-6, those from Cand Tho University are MLT105 and MLT250, and that from SASSI is VND95.

[10] They are IR50404, IR56279, and IR64.

TABLE 6

Composition of Modern Varieties by Region and Season in 1996 and 2003

(%)

	North				South			
	Dry		Wet		Dry		Wet	
	1996	2003	1996	2003	1996	2003	1996	2003
TV	0	0	0	0	6	0	27	28
MV1	3	0.5	46	17	0	0	0	0
MV2	11	0.5	46	2	4	2	10	0
MV3	(86)	(99)	(8)	(81)	(90)	(98)	(63)	(72)
MV3 (NARS-N)	68	33	2	20	0	0	0	0
MV3 (China)	18	63	6	60	0	0	0	0
MV3 (NARS-S)	0	0	0	0	47	68	28	58
MV3 (IRRI)	0	3	0	1	43	30	35	14
Total	100	100	100	100	100	100	100	100

MV = modern rice varieties; TV = traditional varieties; NARS-N = national agricultural research systems–North; NARS-S = national agricultural research systems–South; IRRI = International Rice Research Institute.

The change in the MV compositions by regions and seasons from 1996 to 2003 is reported in Table 6. The figures confirm our conjecture that the Vietnam's Green Revolution in this period is characterized by the replacement of MV; in the North, the MV3 (China) massively took over the MV3 (NARS in North) in the dry season and over the MV1 and the MV2 in the wet season, whereas in the South the replacement occurred from the IRRI's MV3 to MV3 (NARS in South). It is important here to remind about Vietnam's diversified production environments from the North to the South. The key to continuous replacement to superior varieties in Vietnam seems to lie in the success in finding and importing suitable varieties developed in the countries with the similar production environments, as well as in developing location-specific varieties by NARS in each region.

B. *Determinants of Modern Varieties Adoption*

What type of farmers supported the Green Revolution process characterized above? To answer this question, we estimate the reduced-form MV adoption function. In our preliminary analysis we found that among MV3 users, no significant difference was observed in household characteristics in the choice of a specific MV3 (which is therefore not shown in a table). This implies that once the farmers become MV3 users, their socioeconomic conditions do not matter in the replacement among them. Therefore, the relevant question here is who can climb up a MV ladder from TV to MV1, then to MV2, and finally to MV3. For this purpose, we construct a discrete dependent variable such that TV = 0, MV1 = 1, MV2 = 2, and MV3 = 3, and apply the ordered logit analysis. In the analysis of data in 2003, we combined MV1 and MV2 together as each has small number of observations. The explanatory variables we use include: (i) socioeconomic variables such as total paddy area (in natural log), the number of family workers (in natural log), age of household head, schooling years (those of household head in 1996 analyses or the average schooling years of the members engaged in agriculture in 2003 analyses), and male household head dummy; (ii) irrigation dummy for wet season and dry season dummy; and (iii) agroecological region dummies using RRD as the base.[11]

Table 7 shows that dry season dummy is highly significant in both years, indicating that under irrigated conditions farmers are faster in climbing up the MV ladder, as shown also in the Philippine and Bangladesh studies. Reflecting the increasing importance of careful water management for latest MV, the impact of irrigation emerges even during the wet season in 2003. The coefficient of schooling is highly significant in 1996 and weakly so in 2003. Another significant variable is farm size in 2003 whose negative sign indicates that the recent MV technologies are more small-farmer friendly. As expected, we find no significant difference between male and female household head families.

C. *Estimation of Yield Functions*

The contribution of MV from different origins to the rice yield is examined by estimating the reduced form rice yield function for the years of 1996 and 2003. For this purpose, we incorporate dummy variables for different origins of MV3, using TV and earlier generation MV together as base: i.e., *mv3north*, *mv3china*, *mv3south*, and *mv3irri*.[12] To capture differential impacts between the seasons, the MV dummies are interacted with dry season dummy. As a result of a strong correlation between irrigation status and MV3 adoption, irrigation dummy per se is not included, and thus MV dummies would also capture the effect of irrigation. The same socioeconomic variables are used. To control for agroecological differences, we include regional dummies using RRD as based.

The estimation results are reported in Table 8. The analysis of 1996 data shows that significant contribution was made by adoption of MV3 developed by NARS in the South or by IRRI in the dry season. Meanwhile, the potential of MV3 had yet to be achieved in any seasons in the North, regardless of the moderate level of MV3

[11] The survey in 1996 asked only about household head's characteristics. We use the household head's schooling years as the best alternative of average schooling years. In the analyses of the survey in 2003, we find that the replacement of the head's schooling years with the average schooling years does not alter the qualitative results. This implies the results of the survey in 1996 would not change either even if average schooling years were used.

[12] We assume the recursive systems of MV adoption and its yield effects.

TABLE 7

Determinants of the Adoption of Modern Varieties in 1996 and 2003, Ordered Logit Estimation

Dependent Variables	1996 TV = 0, MV1 = 1, MV2 = 2, MV3 = 3	2003 TV = 0, MV1&2 = 1, MV3 = 2
Socioeconomic variables:		
Irrigation (wet season)	0.377	3.073
	(1.45)	(4.09)***
Dry season	2.68	3.984
	(10.4)***	(7.38)***
ln *(farm size)*	0.208	−0.521
	(1.30)	(2.35)**
ln *(working member)*	−0.208	0.139
	(1.02)	(0.46)
Age	0.027	0.018
	(3.13)***	(1.46)
Schooling†	0.120	0.109
	(3.07)***	(1.71)*
Male HH head	0.027	−0.058
	(0.13)	(0.15)
Regional dummy:		
Outer MRD	−0.375	−1.19
	(1.20)	(1.86)*
MRD	4.724	32.13
	(4.40)***	(0.00)
NMH	−0.613	−0.422
	(2.80)***	(0.96)
Log likelihood	−494.9	−199.7
LR χ^2	376.3 [0.00]	332.9 [0.00]
Pesudo R^2	0.28	0.45

Note: Absolute value of z-statistics in parentheses; p-values in brackets.
† The "household head's schooling years" is used in 1996 analysis and the "average schooling years over working agricultural member" is used in 2003 analysis.
***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.
HH = household head; MRD = Mekong River Delta; MV = modern rice varieties; NMH = North Mountain Highlands; TV = traditional varieties.

adoption rate. This structure was changed, however, in 2003: the results show that MV3 developed by NARS in the North and those imported from China significantly contributed to the increase in the rice yield in both wet and dry seasons, although no significant advantage was observed in the dry season. In fact, the Chinese variety called Khang Dan was newly introduced to Vietnam in this period, and as we have seen in Table 6, switching to that variety occurred swiftly both in dry and wet seasons. In the South, MV3 from NARS and IRRI in the dry season created stronger impacts in 2003 than they did in 1996. Furthermore, MV3 from NARS in the South,

TABLE 8

Estimation Results of ln (Rice Yield) Functions in 1996 and 2003, OLS Analysis

	1996	2003
MV dummy:		
mv3north	0.125 (0.93)	0.260 (3.11)***
mv3china	0.027 (0.27)	0.230 (3.68)***
mv3south	−0.006 (0.08)	0.113 (1.86)*
mv3irri	0.015 (0.26)	0.043 (0.50)
mv3north∗dry	0.054 (0.39)	−0.046 (0.62)
mv3china∗dry	0.104 (0.96)	0.058 (1.23)
mv3south∗dry	0.258 (3.80)***	0.309 (6.52)***
mv3irri∗dry	0.395 (6.59)***	0.464 (5.64)***
Sociceconomic variable:		
ln *(farm size)*	−0.049 (2.63)***	−0.081 (3.78)***
ln *(working member)*	0.000 (0.01)	−0.052 (1.87)*
Age	−0.001 (0.82)	−0.001 (0.67)
Schooling†	−0.007 (1.39)	0.030 (5.05)***
Male HH	−0.063 (2.05)**	−0.001 (0.02)
Regional dummy:		
Outer MRD	−0.149 (3.11)***	−0.047 (0.55)
MRD	0.462 (6.49)***	0.593 (5.54)***
NMH	0.156 (3.93)***	0.198 (4.24)***
Constant	8.451 (77.84)***	8.248 (65.02)***
R^2	0.46	0.43

Note: Absolute value of *t*-statistics in parentheses.
† The household head's schooling years is used in 1996 analysis and the average schooling years over working agricultural member is used in 2003 analysis.
***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.
HH = household head; MRD = Mekong River Delta; MV = modern rice varieties; NMH = North Mountain Highlands; TV = traditional varieties.

TABLE 9

Factor Payments and Shares, 1996 and 2003

(US$, %)

	1996		2003	
	TV	MV	TV	MV
Gross value of output	291 (100)	565 (100)	334 (100)	624 (100)
Total cost	337 (116)	487 (86)	284 (83)	459 (74)
Current inputs	54 (19)	158 (28)	54 (16)	157 (25)
Capital services	5 (2)	21 (4)	39 (11)	54 (9)
Labor payments	278 (95)	308 (55)	191 (56)	248 (40)
Residual profit	−46 (−16)	78 (14)	60 (17)	164 (26)
Yield (ton/ha)	2.5	4.2	2.7	5.2
Unit cost (US$/ton)	134	115	105	88
Price (US$/ton)	116	134	117	132
Price/cost	0.87	1.16	1.11	1.65

MV = modern rice varieties; TV = traditional varieties.

mv3south, contributed also to the improvement in the wet season rice cultivation. In this period, new series of MV characterized by small and long grain, and short maturity of approximately 85–90 days, were released from CLRRI. These varieties can be suitably grown even in wet and flooding conditions. Subsequently, switching from IRRI varieties to these NARS varieties occurred as shown in Table 6. Note that IR64 had been the major variety grown in both periods. Hence, the greater magnitude of the coefficient of *mv3irr∗dry* in 2003 than in 1996 would be because of the yield-enhancing effect of IR64.

The coefficients of farm size are consistently negative and significant in both periods, supporting the hypothesis of inverse relationship between farm size and yield, as seen also in the Philippines' study. Schooling is significant only in 2003, implying that rice cultivation is becoming more knowledge intensive. One interesting result is negative and significant coefficient of the male household head dummy in 1996 regression.

D. *Factor Share Analysis*

The estimates of the factor payments and unit cost of rice production in 1996 and in 2003 are reported in Table 9. The differences of factor shares between TV and MV shows a similar pattern to other Asian tropics; the share of current inputs is appreciably higher for MV than for TV in both years, indicating increased fertilizer use for

MV. The changes over time also show a similar pattern to other Asian tropics. The share of labor payments for MV production declined from 55% in 1996 to 40% in 2003 as a result of the widespread of labor-saving technologies, such as tractor and thresher. Meanwhile, the share of capital services shows marginal increase partly because of underdevelopment of rental markets for such technologies.

The impact of the replacement among MV3 might be measured by the increase in residual profit that is a measure of production efficiency or by the reduction in the unit cost of production. The residual profit increased from US$78 in 1996 to US$164 in 2003 by 110%. The unit cost declined from US$115 per ton to US$88 per ton during the same period. Unlike in the case of Bangladesh, the major reason for this reduction was the increase in yield from 4.2 to 5.2 tons per hectare.

We also compute the differences in the factor payments in different MV3 under irrigated and rainfed conditions (which are not shown in the tables). The results show that MV3 generate positive and high residual profit under irrigated conditions, but not so under the rainfed condition. Once again, this result supports the finding by Tran, Hossain, and Janaiah (2000); MV generate net benefit for rice cultivators when they are supported by good irrigation and drainage systems. The residual profit becomes highest for the farmers who cultivate MV3(IRRI) or MV3(NARS-S) under irrigated conditions in the dry season, indicating their large-scale operations in less labor-intensive manner, compared with the northern region in which the farm size is much smaller than in the South.

V. CONCLUDING REMARKS

In the current paper, we have reviewed the development of the Green Revolution in Vietnam, using long-term regional yield and MV adoption statistics, as well as household data collected by our own surveys. The Green Revolution began in irrigated favorable areas and spread to the less favorable areas in Vietnam, which is similar to other Asian countries (David and Otsuka 1994). Also similar is the utmost importance of production environments in determining the adoption of MV and its impacts on productivity.

The case of Vietnam, however, is unique in that the Green Revolution practically started in the late 1970s after the end of Vietnam War in 1975, when the so-called second-generation MV resistant to pests and diseases were already available (Estudillo and Otsuka 2006). An interesting observation is that while the Green Revolution ended in the mid-1980s in the Philippines, it has still been sustained in Vietnam as of 2003. Indeed, the growth performance of rice sector in Vietnam in the 1980s and 1990s outweighs any other Asian countries. Such growth has been supported by continuous improvements of MV. In this process, the varieties imported from China contributed to the Green Revolution in northern Vietnam and those developed by IRRI in southern Vietnam. The regional agricultural research institutes and agricultural universities have played a critically important role in developing location-specific and appropriate technologies. This point is amply supported by the data on adoption of various MV of different origins in 1996 and 2003.

In short, the outstanding success of the Green Revolution in Vietnam exemplifies the importance of both technology transfers from other countries and regional-level adaptive research undertaken by the national research programs. In all likelihood, in order for sub-Saharan Africa to realize a Green Revolution, far greater efforts would be required to import technologies from abroad (possibly Asia) and assimilate them to suit the production environments in this region vastly different from countries where the Green Revolution has already taken place.

REFERENCES

Bui, Ba Bong. 2000. "Genetic Improvement of Rice Varieties for the Mekong Delta of Vietnam: Current Status and Future Approaches." In *Rice Research and Development in Vietnam for the 21st Century*, ed. Bui Ba Bong. Can Tho: Cuu Long Delta Rice Research Institute.

David, Cristina C., and Keijiro Otsuka, eds. 1994. *Modern Rice Technology and Income Distribution in Asia*. Boulder, Colo. and Manila: Lynne Rienner Publisher and International Rice Research Institute.

Estudillo, Jonna P., and Keijiro Otsuka. 2006. "Lessons from Three Decades of Green Revolution in the Philippines." *Developing Economies* 44, no. 2: 123–48.

International Food Policy Research Institute (IFPRI). 1996. *Rice Market Monitoring and Policy Options Study*. Washington, D.C.: IFPRI.

Irvin, George. 1995. "Vietnam: Assessing the Achievement of Doi Moi." *Journal of Development Studies* 31, no. 5: 725–50.

Pham, Thi Mui, and Bui Ba Bong. 1999. "Evaluation of Rice Varieties for Resistance to Brown Plant Hopper in the Mekong Delta." *Omon Rice Journal* 7, 5–11.

Pingali, Prabhu, and Vo-Tong Xuan. 1992. "Vietnam: Decollectivization and Rice Productivity Growth." *Economic Development and Cultural Change* 40, no. 4: 697–718.

Tran, Dat V. 2001. "Tiến trình sản xuất lúa tại Vietnam và sự cần thiết thay đổi cơ cấu trong tương lai" [Progress in rice production in Vietnam and the necessity for structural changes in the near future]. In *Lúa Việt Nam: thế kỹ thứ 20. Nguyễn* [The Vietnam rice: 20th century], ed. Nguyen Van Luat. Hanoi: Agriculture Publisher.

Tran, Thi Ut; Mahabubu Hossain; and Aldas Janaiah. 2000. "Modern Farm Technology and Infrastructure in Vietnam: Impact on Income Distribution and Poverty." *Economic and Political Weekly* 35, nos. 52–53: 4638–43.

Vo-Tong, Xuan. 1995. "History of Vietnam—IRRI Cooperation." In *Vietnam and IRRI: A Partnership in Rice Research*, ed. Glenn L. Denning and Vo-Tong Xuan. Manila: International Rice Research Institute.

Young, Kenneth B; Eric J. Wailes; Gail L. Cramer; and Ngyen Tri Khiem. 2002. "Vietnam's Rice Economy: Developments and Prospects." University of Arkansas Division of Agriculture, Research Report no. 968. Fayetteville: University of Arkansas.