The Australian Journal of Agricultural and Resource Economics, 48:1, pp. 95–126

Agricultural dynamics in Thailand, Indonesia and the Philippines

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The introduction of new high-yielding varieties of cereals in the 1960s, known as the green revolution, dramatically changed the food supply in Asia, as well as in other countries. In the present paper we examine, over an extended period, the growth consequences for agriculture in Indonesia, Thailand and the Philippines. Despite geographical proximity, similar climate and other shared characteristics, gains in productivity and income differed significantly among the countries. We quantify these differences and examine their determinants. We find that the new technology changed the returns to fertilisers, irrigated land and capital, all of which proved scarce to varying degrees. Complementing technology-related changes in factor use were investments, public and private, driven in part by policy. We find that factor accumulation played an important role in output growth and that accumulations from policy driven investments in human capital and public infrastructure were important sources of productivity gains. We conclude that policies that ease constraints on factor markets and promote public investment in people and infrastructure provide the best opportunities for agricultural growth.

1. Introduction

The present paper analyses the determinants of agricultural growth and various aspects of the agricultural dynamics in Thailand, Indonesia, and the Philippines, from the 1960s until the late 1990s. The point of departure is the reliance on the choice of techniques framework. The analysis uses time-series data, which are subject to multicollinearity. We overcome this problem by using a principal component technique. The substantive economic aspects of the agricultural dynamics in the sample countries are emphasised, while the technical issues are suppressed. The present paper is based on a working paper (Mundlak *et al.* 2002) that provides additional details and discussion and relates to the published literature dealing with

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Table 1 Selected growth rates (per annum) for Thailand, Indonesia and the Philippines

	Thailand 1961–97	Indonesia 1961–98	Philippines 1961–98
Population	2.23	2.06	2.51
Output			
Agriculture	3.69	3.44	2.55
Total	7.10	6.39	3.61
Per capita			
Agriculture	1.46	1.38	0.04
Total	4.87	4.33	1.10
Agriculture/total	0.30	0.32	0.04

agriculture in Thailand, Indonesia and the Philippines.[1] The countries in question share some common attributes: (i) they are located near one another and have similar climates; (ii) each experienced relatively high rates of population growth (above 2 per cent); (iii) the staple food is rice; and (iv) they all grow tree crops, the output of which is largely export orientated. At the same time, there are striking differences in their overall economic performance over the last three decades; the growth rate of output (gross domestic product (GDP)) in the economy at large was 7.1 per cent in Thailand, 6.4 per cent in Indonesia, and only 3.6 per cent in the Philippines (table 1).[2] The growth rates of agricultural output (GDP) were 3.69, 3.44, and 2.55 for the three countries, respectively. Clearly, nonagriculture grew much faster than agriculture. The rates of growth of per capita output show even sharper differences. Per capita agricultural output grew at an annual average rate of 1.46 per cent in Thailand and 1.38 per cent in Indonesia, while in the Philippines per capita agricultural output barely grew, making difficult the challenge of feeding a growing population. The Philippines was also less successful in raising the overall standard of living economy-wide; per capita income in the Philippines grew at an average rate of 1.1 per cent, as compared to 4.87 per cent in Thailand and 4.33 per cent in Indonesia. Therefore, the Philippines lagged behind in its growth of agricultural as well as of total output. This apparent correlation between total and agricultural performance suggests that there are common factors that affect agriculture and nonagriculture.

[1] Also see Balisacan *et al.* (2004), Shigetomi (2004) and Kawagoe (2004) for in-depth discussions on the political economies of the Philippines, Thailand and Indonesia (respectively).

[2] The growth rates were obtained from trend regressions (natural log of variable on time).

The plan of the present paper is as follows. We begin with a brief review of the empirical background. This is followed by summary results of the empirical production function. The estimated elasticities are used to compute the marginal productivity of inputs and the evaluation of their substantive meaning with emphasis on the developments in the inputs markets. The coefficients are used for the analysis of the sources of growth. Policy implications are drawn, and the discussion is concluded with a summary section. The appendix summarises the technical details of the estimation.

2. Agricultural performance: an overview

Table 2 summarises the changes in agricultural output and inputs by sub periods. The country ranking of output follows the pattern observed in table 1. The time pattern shows a decline in the output growth rate from 1980 onwards. The most drastic change took place in the Philippines, where the rate declined from 3.82 per cent in the period 1961–1980 to 1.38 per cent in the period 1980–1998. In this latter period, the growth rate was less than that of population growth.

For the period as a whole, agricultural labour grew at a slightly lower rate than population; the difference indicates migration of labour to non-agriculture. The exception is Thailand in the boom period of the 1970s when agricultural labour grew at a rate of 3.75 per cent. Land expanded at a slower pace than labour, and therefore the land-labour ratio declined. We differentiate between the growth of irrigated and non-irrigated, or rainfed, land.[3] Irrigated land is more productive for a variety of reasons, but it constitutes a small fraction of the total land. The range in the sample period was 10–12 per cent in Indonesia, 9–14 per cent in the Philippines and 15–25 per cent in Thailand. Its expansion requires investment in water supply and irrigation systems, and it is therefore constrained by the availability of capital. In Thailand and the Philippines the pace of growth of irrigated land exceeded that of labour, and it resembled the rate of output growth. The pace in Indonesia was considerably slower. Indonesia seems to have faced the most severe capital scarcity. The capital-output ratio (in value terms) in Indonesia in 1961 was .07, much lower than in the other two countries. The situation changed as a result of the swift growth of capital. The fast growth of the capital stock resulted in convergence to the order of magnitude in the other two countries. Therefore, in 1996 the ratio was 0.84 in the Philippines, 1.2 in Indonesia, and 2.5 in Thailand. How does it compare with other countries? Mundlak (2000) presents the empirical distribution

[3] Rainfed land is calculated as the difference between agricultural land and irrigated land.

Table 2 Growth rates (per annum) in agricultural output and inputs

			Land				Capital		
		Output	Irrigated	Rainfed	Fertilisers	Labour	Total	Machines	Agricultural origin
Thailand	1971–1995	3.35	3.52	0.61	10.00	2.00	1.80	ND	ND
	1971–1981	3.78	3.82	1.36	11.50	3.75	1.00	ND	ND
	1981–1995	3.22	2.61	0.09	9.96	0.42	3.15	ND	ND
Indonesia	1961–1998	3.44	0.61	0.31	10.13	1.64	11.24	ND	ND
	1961–1980	3.39	0.25	–0.13	12.45	1.11	10.18	ND	ND
	1980–1998	3.04	0.69	0.68	3.69	1.95	12.68	ND	ND
Philippines	1961–1998	2.55	2.64	1.01	5.36	2.17	ND	4.55	3.75
	1961–1980	3.82	3.20	1.42	7.35	2.30	ND	6.64	3.47
	1980–1998	1.38	1.15	0.18	4.90	1.50	ND	0.28	3.35

ND, no data obtained.

of fixed capital-output ratio of 58 countries. The median of this distribution was 1.4 and 1.8 in 1970 and 1990, respectively. Our figures for the Philippines include capital of agricultural origin in addition to fixed capital, and therefore the comparison is obscured.[4] With this reservation in mind, it appears that the capital-output ratio in the Philippines and Indonesia was below the sample median. Fertilisers were the fastest growing input. The fertiliser-land ratio was lowest in Indonesia, which also had the lowest ratio of irrigated land. For the period as a whole, the growth rate was about 10 per cent in Thailand and Indonesia and 5.4 per cent in the Philippines. In all three countries, the rate of growth decreased in the period after 1980. The change is particularly strong in Indonesia. To obtain perspective we note that in USA the growth rate of fertilisers during 1950–1980 was 3.1 per cent, and practically zero thereafter (Gardner 2002). The considerably higher growth rates in Asia underscore the strong impact of the green revolution on the demand for fertilisers in Asia.

3. Empirical model

3.1 Specification

In a world of heterogeneous technology, producers have to choose the techniques of production in addition to the choice of the level of outputs and inputs. The choice is made from the collection of techniques that are available at the time of the decision, referred to as the available technology (AT), and it is affected by the product demand, factor supply and constraints. The variables that affect the choice are referred to as state variables, and are represented by a vector $\boldsymbol{s}$. The subset of techniques that are used in production is referred to as the implemented technology (IT). The formal analysis is described in Mundlak (1988, 2000) and outlined in section (I) of the appendix.

In aggregate analysis, the techniques themselves are not observed, and factor productivity has to be inferred from data aggregated over techniques. However, factor productivity depends on the implemented techniques. For instance, rice output of a country is the sum of outputs obtained from more than one variety, and from the use of more than one practice. The productivity of a unit of fertiliser in the production of traditional rice variety grown on dry land is not the same as that in the production of a high-yielding variety grown on irrigated land. Therefore the productivity of

[4] The coverage of fixed capital data is not well defined. For some comments on this subject, see Larson *et al.* (2000).

fertiliser evaluated from aggregate data will depend on the composition of the implemented techniques.

The heterogeneity in techniques increases when we move from rice to the aggregate of all agricultural outputs. When working with aggregate data, it is impossible to keep track of all the techniques used, and we have to resort to an indirect approach where the productivity is expressed as a function of the state variables that affect the choice of the techniques. Therefore, the aggregate output-input relationships, referred to as the aggregate production function, is represented generically by

$$\ln y = \Gamma(\boldsymbol{s}) + \boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x}) \ln \boldsymbol{x} + u \tag{1}$$

where y is output, $\boldsymbol{x}$ is a vector of inputs, and $\boldsymbol{s}$ is a vector of state variables, $\Gamma(\boldsymbol{s})$ and $\boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x})$ are the intercept and the slope of the function, respectively, and u is a stochastic term. The aggregate production function looks like a Cobb-Douglas function, but there is a major difference from a constant coefficients function in that the coefficients in equation (1) are functions of the state variables and possibly of the inputs. The dependence on inputs is common to the translog function (Christensen *et al.* 1973).

At each sample point, the data are aggregated over the implemented techniques, the composition of which is likely to change over the sample points (see section (II) of the appendix for additional discussion). This approach has important implications for the empirical analysis, summarised by the following properties:

1. Endogeneity: *IT* is endogenous.
2. Jointness: *IT* is determined jointly with the level of intensity at which the inputs are used.
3. Concavity: an aggregate production function which ignores the state variables is not subject to a concavity constraint, even when each of the techniques is represented by a concave production function.[5] The output/production path is therefore determined by the evolution of the state variables.

In this framework, a change in $\boldsymbol{s}$ causes a change in the coefficients of the aggregate function and the inputs. This is an outcome of the endogeneity and the jointness properties. For this reason, strictly speaking, the aggregate production function is not identified. In practice, the problem is less serious when the inputs and the coefficients respond differently to changes in $\boldsymbol{s}$, or to errors in the optimisation. The latter constitutes a major source

[5] In terms of equation (1), an empirical production function, which ignores the state variables, may display increasing returns to scale.

for identification, because those are likely to have a more pronounced effect on the input decisions than on the choice of techniques.

Because the variations in the state variables affect the production function coefficients directly as well as indirectly, through their effect on inputs, estimates obtained under the assumption of constant coefficients are distorted. This is the reason that empirical estimates are sensitive to the choice of sample, and are therefore not robust. This assertion can be demonstrated by evaluating the elasticity of output with respect to a given state variable (say s_i), holding $\boldsymbol{x}$ constant:

$$E_i = \partial \Gamma(\boldsymbol{s})/\partial s_i + \ln \boldsymbol{x}[\partial \boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x})/\partial s_i]. \tag{2}$$

When a production function is estimated under the assumption of constant coefficients, the effects captured by equation (2) are not measured and become a component of the unexplained production function residual. Because the inputs are functions of $\boldsymbol{s}$, they are correlated with $\boldsymbol{s}$, and as a consequence the estimates are biased.

3.2 Estimation

The estimation of equation (1) requires a specification of the functions $\Gamma(\boldsymbol{s})$ and $\boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x})$ in terms of the arguments, $\boldsymbol{s}$ and $\boldsymbol{x}$. When the function $\boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x})$ is expressed as a linear function of $\boldsymbol{s}$ and $\boldsymbol{x}$, product of $\boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x})$ with $\ln \boldsymbol{x}$ yields quadratic terms. Quadratic regressions contain a large number of regressors, which are highly intercorrelated in time-series data. This multicolinearity makes it practically impossible to identify properly the coefficients of the quadratic terms. To overcome this difficulty, the common approach to the identification is to use the factor shares, but this information is not available in our case. We therefore impose constant slopes, but allow the intercept to depend on the state variables. In terms of equation (2), this allows us to capture the impact of the first term on the residual, and thereby to remove the bias resulting from the correlation of the residual and the inputs. To be precise, this eliminates only the linear component of the residual and the inputs, but for linear estimators this is all that matters.

The strong multicolinearity still exists, even when the quadratic terms are eliminated, and this decreases the precision of the ordinary least squares estimates. Consequently, several coefficients are not significantly different from zero, whereas others take on unreasonable values, such as elasticities larger than 1. The elimination of variables with non-significant coefficients is inconsistent with our prior knowledge that the variables belong to the equation. For instance, we do not want to eliminate an important input from the production function. From a formal point of view, the elimination of a variable is equivalent to an imposition of a linear homogeneous constraint on the coefficients of the function. There is a less costly possibility; namely, to impose a constraint in such a way as to eliminate a linear combination of the variables in the equation, instead of a particular variable. In general, when a variable, or a linear combination of variables, is eliminated from a regression, the coefficients of the remaining variables are affected, unless the variables are uncorrelated. This suggests that it is desirable to work with orthogonal (uncorrelated) regressors. This can be achieved by constructing orthogonal linear combinations of variables, referred to as principal components.

The analysis begins with the computation of principal components regression, then the non-significant components are eliminated. The question is which, and how many, principal components to eliminate from the regression. For this we need a criterion. We follow here the approach in Mundlak (1981), which seeks to obtain the tightest confidence region for a given level of significance. We have hence eliminated as many principal components as possible, subject to the restriction that the null hypothesis – that the eliminated coefficients are jointly equal to zero – is not rejected at the five per cent level of significance. Once the statistical rank is determined, the coefficients of the principal components are transformed to the coefficients of the original variables.[6]

3.3 Variables

The dependent variable is the log of agricultural GDP, henceforth output. The inputs are irrigated land, rainfed land, fertilisers, capital, and labour. The state variables are referred to here as carriers of the implemented technology, because they are correlated with that component of the residual which reflects the changes in the implemented technology. The state variables included in the final results are roads, representing the physical infrastructure, measures of education and health representing human capital, and measures of incentives (that is, relative prices of agricultural output). Education is represented by the percentage of agricultural workers who have no schooling for Thailand and Indonesia (referred to as no schooling) and as the mean accumulated school years of the total labour force (education) for the Philippines. The infant mortality rates represent the level of health. Both no schooling and infant mortality declined continuously during the

[6] The initial number of regressors, less the number of linear combinations of the parameters that are not significantly different from zero is referred to as the statistical rank of the matrix of regressors. For a more detailed explanation of the principal components technique, see Mundlak (1981).

period, whereas road length increased. These variables signify the overall development during the period. We have also tried other measures, such as electricity consumption, but strong multicolinearity prevented their inclusion. The variables representing physical infrastructure and human capital are referred to as policy variables, because they are largely publicly financed.

4. Empirical results

4.1 Production function

Our insight on the production structure is drawn from an empirical Cobb-Douglas production function. In this section we present a set of final results, which summarise a detailed discussion in Mundlak *et al.* (2002). Our interest here is to concentrate on the substantive meaning of the results; therefore we do not go into great detail on the technical aspects of the estimation. The results appear in table 3. The upper panel presents auxiliary statistics, the middle panel presents the input elasticities, and the lower panel presents the coefficients of the state variables. Constant returns to scale was not imposed in the estimation. Therefore, the sum elasticities reported in the middle panel is the sum of the estimated elasticities of the five inputs. The elasticities reported in the table are the normalised values,

Table 3 Production function-summary results for Thailand, Indonesia and the Philippines

	Thailand 1971–95	Indonesia 1980–98	Philippines 1971–98
Summary Statistics			
R-square	0.982	0.992	0.984
Durbin-Watson	1.748	1.399	1.078
Statistical Rank	2	1	2
Inputs			
Irrigated land	0.132	0.455	0.155
Rainfed land	0.248	0.230	0.425
Fertilisers	0.061	0.084	0.077
Capital	0.415	0.031	0.163
Labour	0.144	0.199	0.181
Sum of elasticities	0.908	1.009	0.910
State variables			
Price	0.034	0.129	0.320
Price spread	ND	0.164	–0.696
Inflation	–0.323	ND	–0.104
No schooling	–0.009	–0.003	ND
Education	ND	ND	0.213
Roads	0.096	0.073	ND
Infant morality	–0.004	–0.002	ND

ND, no data obtained.

obtained by dividing the estimated elasticities by their sum. Note that for Indonesia, the sum is practically 1, whereas for Thailand and the Philippines the sum is 0.91, so that the impact of the normalisation is somewhat marginal. In a competitive market with full information, the elasticities should equal the factor shares, up to a stochastic error. If the countries use the same technology, the estimates should be quite similar, but they are not. This fact is essential for the understanding of the subsequent discussion.

The elasticity of irrigated land in Indonesia is 0.46, which is quite high. Rainfed land was most important in the Philippines with an elasticity of 0.43. The sum elasticities of the two types of land varied in the range of 0.38 (Thailand) and 0.69 (Indonesia). The impact of the high elasticity of irrigated land in Indonesia will be noticed throughout our discussion. Two circumstances might be related to this result. First, a good part of the irrigated land is in Java, which is by far the most productive island. Second, the share of irrigated land in total land was smallest in Indonesia, which indicates that irrigated land was relatively scarce there.

There is more agreement in the estimates of the fertiliser elasticity, which varied between 0.06 and 0.08. To interpret this result, note that GDP is a value added measure where the cost of raw materials is deducted from total output.[7] Profit maximising firms cannot increase profits by changing the quantity of the raw material away from the optimal level (an example of the envelope theorem). Therefore, the coefficient of fertilisers should be zero, in the sense that there should be no functional distribution from value added to fertilisers. But this is not the case. We return to this below.

There is considerable difference among the countries in the capital elasticity. It is particularly high in Thailand, where the irrigated land elasticity was lowest, and it is particularly low in Indonesia, where the irrigated land elasticity was highest. Thailand had the highest capital-output ratio, and Indonesia had the lowest, and for most of the time period, the difference was substantial. Finally, the labour elasticity was relatively low, in that labour is attributed to less than 20 per cent of total output.

The regression coefficients of the policy variables were significant, and this result was not seriously affected by the choice of other regressors. As anticipated in the foregoing discussion, the inclusion of the state variables in the regression affected the estimated elasticities in the expected direction, namely the sum elasticities became close to one and the individual elasticities were mostly positive. As we show in the discussion of factor growth below, the state variables account for an important part of the changes in the total factor productivity (TFP). This is consistent with the assumption

[7] See section (III) in the appendix for a review of issues associated with the estimation of value added functions.

that the introduction of the more productive techniques was supported by the improvement in these variables.

Unlike for the policy variables, the role of prices was less consistent, although in general the price coefficients had the correct signs. The price effect is pronounced in the Philippines, exists but is not robust in Indonesia, and is not important in Thailand. Price variability was also important in the Philippines. The contribution of prices to growth has several aspects. The regression coefficients of prices represent a direct impact of price variations on output, conditional on inputs. The indirect effect of prices on output is through their impact on the level of inputs and the choice of technology. There is an additional effect, which generally goes unrecognised. When there is a gap between the shadow price of an input and its market price, the employment of the input will eventually rise. Empirical support for this statement is provided by the off-farm migration equation where the income gap between agriculture and nonagriculture generates a flow of labour to nonagriculture. Similarly, for instance, the gap between the marginal productivity of fertilisers and the market price increased the fertilisers supply and consequently their use. This has been the case for all three countries. This situation blurs the impact of prices on output in empirical analysis.

4.2 Shadow prices

We turn now to evaluate the economic meaning of the results. Recalling that output is measured in value, we use the estimated elasticities to recover marginal value products, that is; $\partial y/\partial x_j = \varepsilon_j \bar{y}/\bar{x}$, where ε_j is an estimated elasticity associated with input j, and where inputs (x_j) and output (y) are measured at their average level. This measure of marginal productivity represents a shadow value, which, under perfect circumstances, equals the price of the input. The comparison of the shadow prices to actual prices is hindered by the limited information on factor prices. For this reason we also calculate marginal rates of technical substitution by taking the ratio of the marginal value productivity of a pair of inputs. To facilitate the cross-country comparison, we convert the value terms to constant 1993 USA dollars.[8] The average levels of the shadow prices are presented in table 4. The periods are not identical, but the degree of overlap is substantial. In order to be able to trace the source of cross-country differences, we report also the mean value of the average productivity (y/x_j).

[8] The value data are reported in local currency in constant prices, 1985 for the Philippines, 1988 for Thailand, 1993 for Indonesia. They are converted to USA dollars using the exchange rate for these years: 18.607, 25.34, and 2087 for the three countries, respectively. The result is then adjusted to 1993 values using the US GDP deflator: 1985 = 0.784, 1988 = 0.853, and 1993 = 1.00.

Table 4 Productivity, prices and shadow prices

	Thailand 1971–95		Philippines 1961–98		Indonesia 1971–98	
A. Productivity ($US 1993)	Average	Marginal	Average	Marginal	Average	Marginal
1. Irrigated land	2670	352	6448	1001	5004	2288
2. Rainfed land	559	138	856	363	602	138
3. Fertilisers	8760	538	10 985	842	17 793	1493
4. Capital	0.47	0.20	1.53	0.15	3.07	0.09
5. Labour	548	79	883	160	544	108
6. Machines	ND	ND	92.0	5.7	ND	ND
B. Reported prices ($US 1993)						
1. Wage rate	311		349		493	
2. Fertiliser price	873		921		743	
3. Fertiliser, distortion rate	0.62		0.91		2.01	
C. Marginal rates of substitution						
1. Irrigated to rainfed land	2.54		2.75		16.54	
2. Irrigated land to labour	4.47		6.27		21.21	
3. Irrigated land to wages	1.13		2.87		4.64	
4. Irrigated land to labour adjusted	1.55		1.59		4.88	
5. Irrigated land for capital	1784		6516		24 353	
D. Derived prices ($US 1993)						
1. Irrigated land	2346		6673		15 253	
2. Irrigated land-capital base	2373		8667		32 390	

ND, no data obtained.

4.2.1 Land

The marginal value productivity of irrigated land (1993 US dollars per hectare) is $US352 for Thailand 1971–1995, $US1001 for the Philippines 1961–1998, and $US2288 for Indonesia 1971–1998 (line A1 of table 4). These are the shadow values of the annual rent on irrigated land. The values for Thailand and the Philippines do not vary drastically over time, but they rise considerably for Indonesia. The estimates reflect the estimated elasticities and the average productivity. Outstanding in this comparison is the high elasticity for irrigated land in Indonesia. The average productivity of irrigated land is highest in the Philippines, but it is not much higher than the value obtained for Indonesia. The average productivity of irrigated land is by far lower in Thailand, which also has the lowest elasticity for irrigated land, and hence the low value of the shadow rent.

The shadow rent on rainfed land is $US138 for Thailand and Indonesia and $US363 for the Philippines (line A2). The cross-country comparison is affected by the conversion of the values from local currency to constant 1993 US dollars. To neutralise this effect, as well as others that influence the levels, we examine the ratio of the shadow rent on irrigated land to rainfed land. There are several reasons why irrigated land is more productive and the ratio of marginal value products provides a measure of this difference. The results for Thailand and the Philippines are quite similar, 2.5 and 2.7, respectively (line C1). This is suggestive: at the margin, irrigated land is about 2.5 times as productive as rainfed land. The productivity of irrigated land relative to rainfed land is considerably higher in Indonesia. This reflects largely the high elasticity for irrigated land in Indonesia, to which we alluded above. The variability in the ratio of the averages of the two types of land, or equivalently the share of irrigated land in total land, is not that large: it is quite similar in Indonesia and the Philippines, and about twice as large in Thailand.

4.2.2 Capital

The marginal value productivity of capital is an estimate of the shadow price of the user cost of capital consisting of the interest rate, r, the rate of depreciation, d, and the expected capital gain. Because we deal with long-term averages, we evaluate the result under the assumptions of zero expected capital gain. The resulting marginal value productivities are 20 per cent for Thailand, 15 per cent for the Philippines, and 9 per cent for Indonesia (line A4 in table 4).

In the case of the Philippines, we differentiate between two types of capital: machinery and capital of agricultural origin, mainly livestock and orchards. The former constitutes only about 2 per cent of the latter, and therefore it is ignored in the discussion. It should be indicated, however, that the shadow price on machinery is extremely high; this reflects the very high average productivity of machinery as a result of the low level of the input. The lowest marginal value productivity of capital is obtained for Indonesia. The estimate in Indonesia varied considerably with time; it was high in the early years and it declined later on with the rapid increase in the capital stock in agriculture. We return to this below.

4.2.3 Labour

The marginal value productivity of labour varies between $US79 in Thailand to $US160 in the Philippines (line A5). The big story here is not the cross-country differences, but rather the big gap between the marginal value productivity of labour and the wage rate (also reported in table 4). Note that the wage rates in Thailand and the Philippines are reported as daily wage rates, whereas, for comparison, we need annual wages.[9] The difficulty in determining the annual wage stems from the seasonal nature of agricultural employment and the fact that daily employment in agriculture is not reported; we are left to conjecture how actively they are engaged. We assumed arbitrarily an average of 150 working days per year in agriculture. A substantially larger number would make the gap between the annual wage and the marginal value productivity even higher. By the same token, it would make the labour share unreasonably high. Agricultural labour demand is seasonal, which causes less than full year employment in agriculture for rural labour. Labour time not spent in agriculture is spent in non-agricultural activities, including unemployment. For Indonesia, the data report annual wages, so that the problem of converting daily wages to annual wages does not exist, or it is disguised.[10]

The big difference between the estimated shadow price of labour and the wage rate may arise for several reasons. First, the estimated labour elasticities are possibly biased downward. Yet, the gap between the elasticities and the labour shares is common to all the countries and that weakens the likelihood that the culprit lies in the estimation process. Second, workers classified as agricultural may devote a portion of their time to activities outside agriculture with the consequence that the size of the effectual labour force in agriculture is considerably lower than the reported one.[11] In terms of our calculations, this is another way of saying that the average number of working

[9] Nominal wage rates were deflated by the consumer price index to obtain real wage rates which were converted to $US 1993 following the procedure described in note 8.

[10] For Indonesia we deflated the nominal wages by the GDP deflator.

[11] See Lanjouw and Lanjouw (1995) for a discussion based on household evidence.

days of a reported labour force in agriculture is less than 150 days. Third, the problem is not so much in the reported labour force, but in the mere fact that there is surplus labour and disguised unemployment in agriculture. Fourth, the conversion of the wages from local nominal values to constant USA dollars introduces annual variability in the country data because of the strength or weakness of the local currency. This problem is relevant mainly for Indonesia, but in any event, it cannot account for the big gap between the shadow wage and the calculated wage.

4.2.4 Fertilisers

The foregoing argument that the marginal value productivity of fertilisers derived from the value added function should be zero is valid only for the homogeneous technology with competitive markets for both the product and the raw materials. When this is not the case, or the prices perceived by the farmers are different from those used in the national accounts, the argument does not apply. Specifically, when the supply of fertilisers is not perfectly elastic, the empirical coefficient of fertilisers reflects the shadow price of fertilisers, which is different from the average market price. In this connection, we note that the growth rate of fertiliser use in the three countries was considerably higher than that of the other variables. This suggests that, with time, countries were closing a gap in the excess demand for fertilisers, which, in itself, is inconsistent with the assumption of optimal use under perfectly elastic supply of fertilisers throughout the sample period. The theoretical argument is further modified in the case of heterogeneous technology, where a change in factor supply causes an intertechnique movement. This is believed to be the force behind the continuous excess demand for fertilisers.[12]

In evaluating our results, the estimated marginal value productivity of fertilisers in the value added function is referred to here as the distortion coefficient. To see this consider the problem: choose x so as to maximise $L = py - wx + \lambda(x^c - x)$, where x^c is the constrained consumption of input x, p is the price of output y, and w is the price of input x. The first order condition on the marginal value added function is $p\partial y/\partial x - w = \lambda$. If λ were equal to zero, the competitive unconstrained first order condition would prevail. When value added is used as the dependent variable in a regression, and x is constrained, λ is the deviation of the first order condition from the standard competitive model, and is referred to as distortion. It is measured in units of value added per unit of x. To normalise it, we divide it by w, and

[12] Using household survey data, Larson and Plessmann (2002) estimate an elasticity of 0.09 for fertilisers and find the estimate robust under alternative model specifications.

refer to the ratio as the distortion rate. The distortion therefore reflects the shadow price of the constraints that prevented farmers from reaching the optimal use of fertilisers and would equal zero under the competitive market. This is a measure of the excess demand at the ongoing prices.[13]

The results for the fertilisers' distortion are reported in line A3 of table 4 in the column titled marginal, and those of the distortion rate appear in line B3 of that table. The fertiliser variable is an aggregate of different fertilisers. We have only the price of ammonium sulphate, which is more expensive (price per metric ton) than phosphates and potassium fertilisers. For this reason, the distortion rate is biased downward. The ratios are 0.62 for Thailand, 0.91 for the Philippines, and 2.01 for Indonesia (line B3). We return to this discussion below.

4.3 Marginal rates of substitution

We turn now to evaluate the factor shadow prices in terms of other factors, based on the marginal rate of factor substitution. We have already presented the results of the marginal rate of substitution of rainfed land for irrigated land. The marginal rate of substitution of labour for irrigated land is the ratio of the marginal value productivity of irrigated land to labour (line C2 in table 4). The unit of the marginal value productivity of labour is output per year of labour worked in agriculture, but not specifically on irrigated land. This ratio is the imputed rent on land measured in terms of labour years. Another approach is to use the wage rate rather than the derived marginal value of labour. The results (line C3 in table 4) show that the imputed rent on a hectare of irrigated land is equivalent to labour income of 1.1 years in Thailand, 4.6 years in Indonesia, and 2.9 years in the Philippines. All these values indicate scarcity of irrigated land relative to labour.

The values in line C3 are lower than those reported in line C2. This may be related to the fact that the production on irrigated land and rainfed land represent different techniques. Computing the marginal rates of substitution directly requires knowing how inputs used in production are allocated between irrigated and rainfed lands. The data do not reveal this allocation, so additional assumptions are required. We proceed under the assumption that a hectare of irrigated land requires 2.5 times as much labour as rainfed land. This ratio is inspired by the ratio of the marginal value productivity of the two lands. We illustrate the computation of the labour requirements

[13] This is considered here to be the main reason, but there may be others, such as a difference between the price of fertilisers used in the national accounts and the cost at the farm gate.

for irrigated land for the case of Thailand. The total labour input is: $L = L_i + L_r$ where the subscripts i and r signify irrigated and rainfed land. Setting the requirement on a hectare of rainfed land as 1, and that of irrigated land at 2.5, then the ratio of labour on irrigated land to total labour is: $L_i/L = 2.5A_i/(2.5A_i + A_r)$ where A_i and A_r represent the area of the two lands. The ratio of averages in Thailand was $A_i/A_r = 0.212$. By substitution, $L_i/L = 2.5/(2.5 + 1/0.212) = 0.346$; that is, about 34.6 per cent of labour in agriculture was allocated to irrigated lands, according to this calculation. Repeating this calculation we get 0.253 and 0.233 for the Philippines and Indonesia, respectively. With this assumption, the marginal rate of substitution of adjusted labour for irrigated land is obtained as the ratio of the marginal value productivity of irrigated land and that of adjusted labour. The results are 1.6 labour years per hectare for Thailand and the Philippines and 4.9 for Indonesia (line C4). The gap between these values and those in line C3 are by far smaller than the gap between the values in lines C2 and C3. The adjustment affects mostly the result for Indonesia. The difference between the various estimates indicates that there are several labour markets that are not perfectly connected and hence the difference in the marginal value productivity.

What do the estimates imply about the value of land? To estimate the value of land, we capitalise the annual shadow rent. In this exercise we discount with an interest rate of 0.15. Line D1 presents the capitalised value of the shadow rent of line A1. The results are roughly $US2300, $US6700, and $US15 300 (1993 USA dollars) per hectare for Thailand, the Philippines, and Indonesia, respectively. By international standards, the value for Indonesia is somewhat high, and that of Thailand is perhaps low. Instead of discounting with $r = 0.15$, we can use the shadow rate. The marginal rate of substitution of capital for irrigated land, is $m(A)/m(K)$.[14] This ratio is reported in line C5. To derive estimated land value, we impose the equality $m(A)/m(K) = R/(d + r)$, where R is the rent on land. We extract from this equality the capitalised value of land, R/r, by assuming that $d/r = 1/3$. The results appear in line D2. A comparison of lines D1 and D2 reflects the difference in the discounting rate. For Thailand the values are practically the same because the shadow value of r is nearly 0.15, which is 3/4 of line A4. The difference for the other two countries reflects the fact that the shadow interest rate is lower than 0.15. Still, the country ranking and differences in the order of magnitude are maintained.

[14] Unlike for the case of labour, we do not differentiate here for allocation of capital between irrigated and rainfed land. Much of the capital is in trees (which are rainfed) and livestock and therefore cannot be directly related to irrigated land.

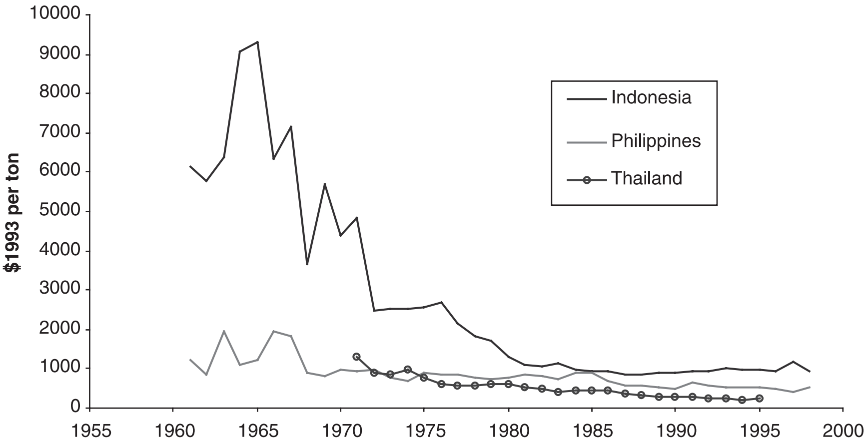

Figure 1 Marginal value productivity of fertiliser.

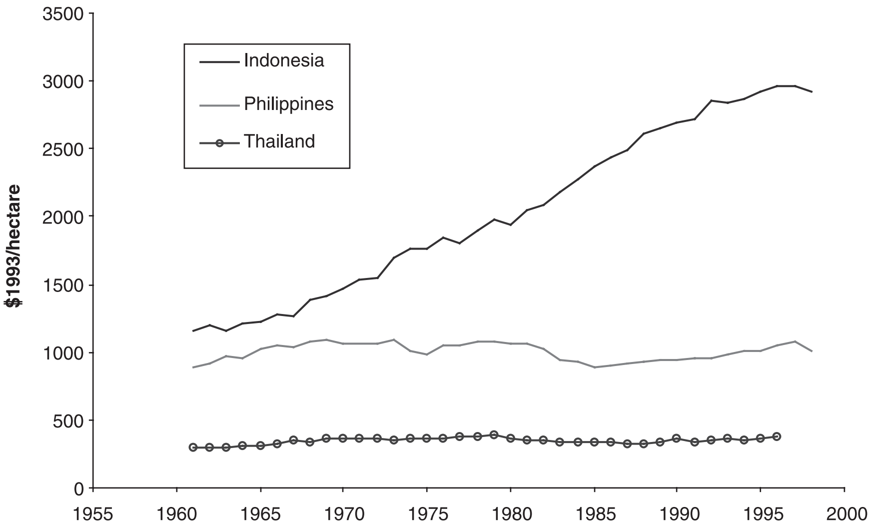

Figure 2 Marginal value productivity of irrigated land.

4.4 Changes over time

The time profiles of the marginal factor productivity are plotted in figures 1–5.[15] There is distinct growth in the marginal value productivity of rainfed land and labour and a decline in that of fertilisers in the three countries. The pattern of the other two factors is less uniform. The marginal value

[15] The marginal productivity values are derived from the production-function parameters. See the discussion relating to table 4.

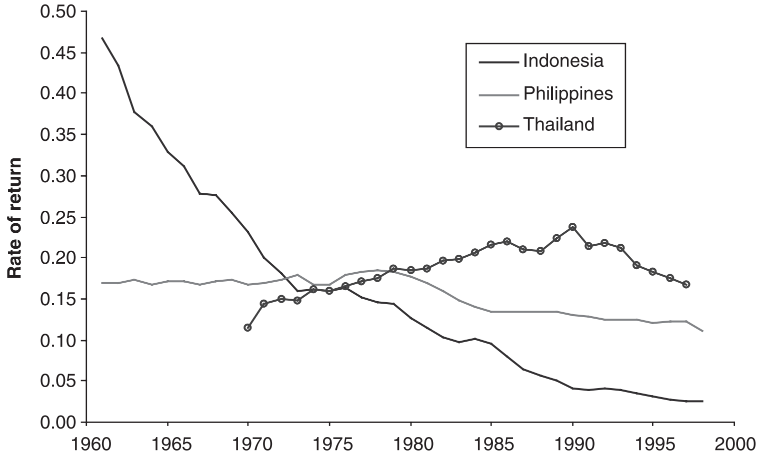

Figure 3 Marginal value productivity of capital.

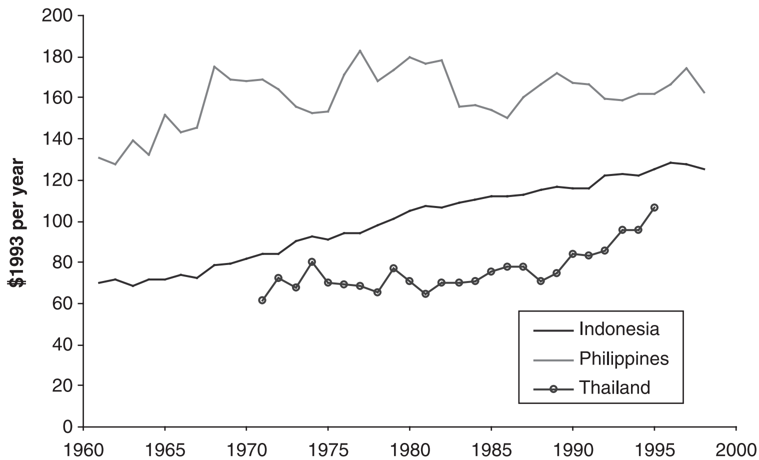

Figure 4 Marginal value productivity of labour.

productivity of capital decreases and that of irrigated land increases remarkably in Indonesia, and to a lesser extent in the Philippines. The pattern in Thailand is not monotonic.

The country differences in the level of the marginal value productivity reflect differences in the elasticities and in the average productivity, and as such are sensitive to the results of the regression analysis. On the other hand, with a Cobb-Douglas production function, the time variations reflect only changes in the average productivity because the elasticities are constant over time. For this reason, the trajectory is independent of the regression analysis. The investigation of the trajectory of the marginal value productivity therefore is reduced to examining the average productivities.

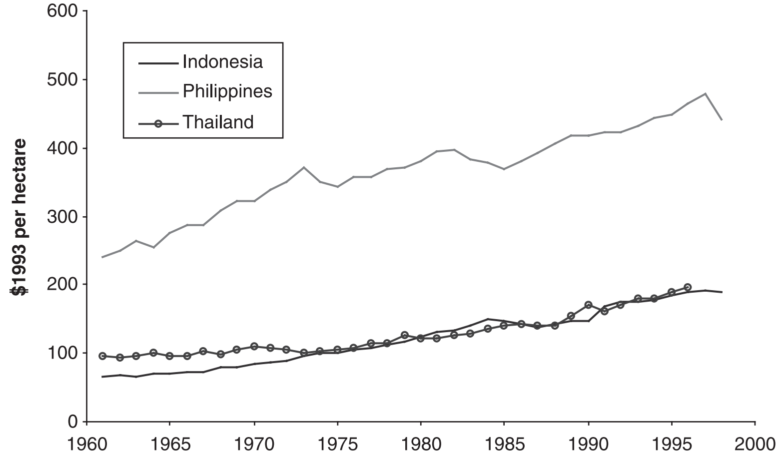

Figure 5 Marginal value productivity of rainfed land.

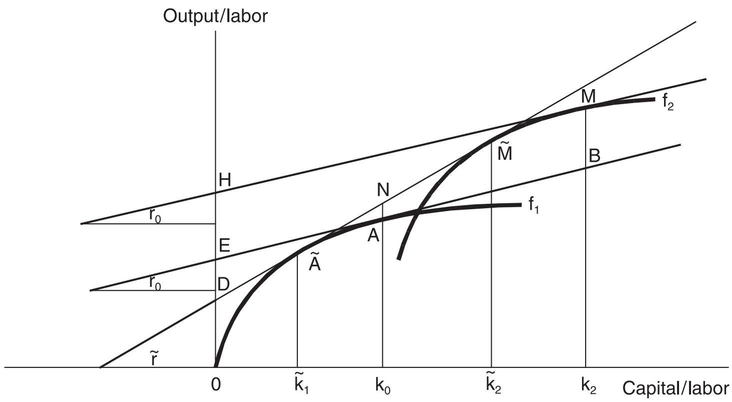

Figure 6 Resource constraint and the choice of technique.

Since the output in the average productivity is the same for all factors, the analysis is further reduced to the analysis of the changes in factor demand and supply. Conceptually, we know how to derive the demand when the technology consists of one production function. The situation is more complex when there is more than one technique. To do this, we turn to the paradigm of economic decisions in the case of heterogeneous technology.

The discussion is conducted with reference to a simple graphical illustration presented in figure 6 (Mundlak 2000). Consider an economy with two inputs, capital (K) and labour (L), producing output Y. Initially the available technology (AT) of the economy consists of only one technique represented by f_1, which expresses the output-labour ratio y as a function of the capital-labour ratio k. The economy is at A with wage rate $(w) = OE$, and the return to capital is r_0. Technical change takes the form of an appearance of a new technique f_2, which is capital-intensive compared to f_1, and the *AT* consists now of the two techniques, $\{f_1, f_2\}$. Holding L constant for simplification, the response of the economy to the technical change depends on factor supply, and this is demonstrated by some extreme possibilities:

1. The supply of K is perfectly elastic – the economy moves to M with r_0 unchanged, but w increases to OH.
2. The supply of K is perfectly inelastic – in this case the best strategy is to choose a convex combination of the two techniques as given by N. The resources are allocated between the two techniques. In this it is assumed that there are no setup costs involved in the implementation of the new technique. When setup costs exist, it is required that the gain from the implementation of the new technique covers the setup costs involved in the implementation, otherwise f_2 is not implemented and the economy stays at A. Similarly, when the new crop is suitable to some regions and not to others, the technical change will not apply uniformly to all regions.

The move from A to N causes a rise in the return to capital from r_0 to $\tilde{r}$ and a decline of w from OE to OD. In reality, there are more than two factors, there are many techniques, and setup costs sometimes prevail. Still, this framework may help us to understand the data. Therefore, we have illustrated that a change in the *AT*, when factor supply is not perfectly elastic, causes a rise in the return to the scarce factor and a decline in that of the abundant factor. This change in prices reflects the change in the factor demand. The price change induces factor mobility, the pace of which depends on the factor supply. In terms of our illustration, ignoring the setup costs, the composite production function is the locus $0\tilde{A}\tilde{M}$ and thereafter along f_2. The output at point N is a convex combination of the outputs at $\tilde{A}$ and $\tilde{M}$.

Returning to the data, the change brought about by implementing the new technology was intensive in fertilisers, irrigation and capital, and extensive in labour and rainfed land. The response of the factors to the change in demand reflected the supply conditions. The strongest response was in fertilisers, which exceeded the growth in output, therefore causing a decline in the average productivity and hence in the marginal value productivity. This is in spite of the fact that the response was not strong enough to eliminate the distortion. The strongest response was in Indonesia where the initial fertilisers-output ratio was rather low. A somewhat similar situation is observed for capital in Indonesia. The rise in the shadow price of capital drew capital to agriculture at a rate exceeding considerably that of output growth and consequently the marginal value productivity declined. The situation in Thailand and the Philippines was less dramatic, but in both countries the flow of capital to agriculture exceeded the growth in output and consequently the marginal value productivity started to decline.

The change in irrigated land in Thailand and the Philippines was roughly similar to the change in output so that there was no dramatic change in the marginal value productivity. In contrast, in Indonesia, the rate of growth of irrigated land was much smaller than that of output and consequently the marginal value productivity increased drastically for the whole sample period. The slow pace of growth relative to the other countries may reflect a more serious capital constraint and perhaps the quality of the potential projects.

The demand for rainfed land was not as favourably affected as that of irrigated land. Consequently its expansion was slower than that of output; therefore the average and marginal value productivity grew in the three countries. A similar situation is observed in labour, which grew at a slower pace than output. The growth of the labour in agriculture reflects the natural growth rate of the rural population, slow off-farm migration, and perhaps data problems, alluded to above (Butzer *et al.* 2003).

5. Growth accounting

Agricultural technology improved dramatically during the period of the present study. This change in the available technology affected factor prices and their supply, and this in turn resulted in productivity growth. The changes that took place over time are summarised in the growth accounting in table 5.[16] We do not identify here the particular measures used for education or prices in each country, but place them in the same category (for details, see Mundlak *et al.* 2002).

The table presents the growth rate of output, total factor, total factor productivity (TFP), and the impact of the state variables. In all countries, the growth rate of output in the first period (up to 1980 or 1981) was fairly similar, about 3.8 per cent for Thailand and the Philippines, and 3.7 per cent for Indonesia. The rates declined in the second period from 1980 on, and most of the decline occurred in the TFP, not in the total factor. This is true in all the countries, but the magnitude of the decline varied, the steepest decline was in the Philippines, from 0.98 per cent in 1961–1980 to 0.13

[16] Note on the calculations in table 5. Let ε represent elasticities and g growth rates and the subscripts i, s, and y represent, respectively, inputs, state variables and output. Then factor accumulation, in percentage terms, is given by $G_i = \Sigma_i\, \varepsilon_i g_i$, where input elasticities have been normalised so that $\Sigma_i\, \varepsilon_i = 1$. Growth in state variables is given by $G_s = \Sigma_s\, \varepsilon_s g_s$. Shares of growth resulting from factor accumulation, P_i, and as a result of changes in the state variables P_s, are given by $P_i = G_i/g_y$, and $P_s = G_s/g_y$. The share of output growth resulting from total factor productivity $(TFP) = 1 - P_i$, and the portion of productivity as a result of changes in the state variables $(SP) = P_s/TFP$. Growth rates used in the calculations are mostly obtained from trend regressions of the type $\ln x = c + b * time$, where $g = b * 100$. Exceptions are made for variables already represented as ratios: inflation, price spread, no schooling and infant mortality, where the regression $x = c + b * time$ is used.

Table 5 Sources of growth in agriculture for Thailand, Indonesia and the Philippines

	Percentage change			Share of output growth		
Philippines	1961–1998	1961–1980	1980–1998	1961–1998	1961–1980	1980–1998
Output	2.55	3.82	1.38			
Factor accumulation	2.30	2.84	1.26	0.90	0.74	0.91
TFP	0.25	0.98	0.13	0.10	0.26	0.09
State variables				0.13	0.18	0.14
Portion of TFP resulting from state variables				1.25	0.72	1.51
Indonesia	1971–1998	1971–1981	1981–1998	1971–1998	1971–1981	1981–1998
Output	3.39	3.69	3.04			
Factor accumulation	1.90	2.10	1.56	0.56	0.57	0.51
TFP	1.49	1.58	1.49	0.44	0.43	0.49
State variables				0.43	0.42	0.47
Portion of TFP resulting from state variables				0.97	0.97	0.97
Thailand	1971–1995	1971–1981	1981–1995	1971–1995	1971–1981	1981–1995
Output	3.35	3.78	3.22			
Factor accumulation	2.26	2.50	2.35	0.68	0.66	0.73
TFP	1.08	1.27	0.87	0.32	0.34	0.27
State variables				0.38	0.30	0.24
Portion of TFP resulting from state variables				1.16	0.89	0.89

TFP, total factor productivity.

per cent in 1980–1998. The mildest change was in Indonesia, from 1.58 per cent in 1971–1981 to 1.49 per cent in 1981–1998.

This seems like a paradox where the technical change is recorded more as a change in total factor rather than in the TFP. This is, however, consistent with changes that take place during the transition to more advanced techniques that are intensive in scarce resources (Mundlak 2000). It is an indication that the magnitude of the TFP is path dependent, in that it depends on the factors' supply. This can be easily seen from figure 6. When factor supply is perfectly elastic, the economy moves from A to M, and the change in the TFP is given by BM. When factor supply is not perfectly elastic, initially the TFP is given by the move from A to N, which exhausts the output growth in the first period. With time k rises and the economy will move along the tangent $\tilde{A}\tilde{M}$, which is associated with the new factor prices. Along this segment the technical change is fully absorbed by the change in the factor prices and the TFP remains unchanged. The upshot is that the computed TFP is path dependent.

The state variables altogether accounted for a large proportion of the TFP growth. They practically exhausted it in Indonesia. There is some variability in each country in the performance between the two periods. The elasticities used in the calculations are the same for the whole period, and it is therefore natural that there will be over and under shooting for shorter sub periods. The overall record, nevertheless, indicates that the state variables serve well as carriers of the implemented technology shocks.

Some details not shown in the table are: roads, as a representative of physical infrastructure, accounted for 11–15 per cent of output growth in Thailand and Indonesia. This variable was not included in the regression for the Philippines. Schooling had a similar contribution, with some variability over time, as did infant mortality as a measure of health. The price variable had a substantial contribution; in Indonesia it accounted for 10 per cent of output growth in the second period and 5 per cent for the period as a whole. In the Philippines, where the prices varied considerably more than in other countries, it contributed about 15 per cent in each of the two periods, but with different signs, so the net contribution was nil for the period as a whole. Overall, the contribution of the price spread was negligible.

6. Policy implications

The purpose of the analysis is to understand the undergoing processes, which is a necessary condition for evaluating roles for positive policies. At the level of aggregation of this analysis, we can assess two subjects, growth and income distribution.

The underlying fact is that there were some important changes in the available technology related to agriculture. In addition, there was an important development in nonagriculture in all three countries. The input requirements of the new technologies were skewed in the direction of capital inputs, mainly irrigated land, fertilisers and other forms of capital. By definition, capital is scarce, and therefore the implementation of the new technologies stretched over a long period of time. This is on the supply side, whereas on the demand side, the countries had to expand their exports in order to supplement the growing domestic demand in absorbing the growing supply. The pace of growth was determined largely by the flow of resources to agriculture, and this is reflected in the weights these inputs receive in accounting for the output growth. The message for the future is clear: for the growth to continue, the available technologies must continue to grow. Without such growth, the impact of input growth will eventually decline; we see some evidence to this effect already in the later years of the present study period. But this is not the only determinant of future growth. In order to take full advantage of new techniques, there must be a smooth flow of the required resources into agriculture. Learning from past experience, it would have been much more productive to respond without delay to the jump in fertilisers demand generated by the green revolution by allowing imports rather than relying solely on home production. The grains output forgone because of the anti import bias would have paid nicely for the imported fertilisers.

The state variables indicate that the public goods are important in facilitating the implementation of the new technologies. Physical infrastructure, like roads, integrates areas with major markets and reduces the cost of transactions. Other variables such as electricity, which did not enter the analysis because of the high correlation with roads, have their own important impact. Investment in such projects is not immediately connected with agricultural programs, but nevertheless, has a strong impact on agricultural growth, and of course on the welfare of the rural population. This is also the case with health and schooling. The investment in such programs is constrained by resource availability, and it is in this sense that capital scarcity plays an important role in the determination of the pace of growth.

Assuming that the changes in the available technology facilitate growth, then the focus should be to allow the inputs in demand to flow into agriculture and to avoid a gap between their shadow price and the long-run supply price. This has several consequences: growth will be fastest, and the benefits will be directed mainly to the farmers rather than to the distribution channels that always benefit from shortages. Not independently, the contribution of TFP will increase relative to total factor. The statement on the removal of obstacles to the flow of resources is meant here to be a road signal and not a detailed road map of an elaborate program. The elimination of obstacles has many aspects related to the distribution system, bureaucratic standards, and elimination of monopolistic lacunas along the way. It may not sound like a dramatic program, but its importance cannot be exaggerated.

The new technologies are on the whole labour saving, and this, together with the natural population growth in agriculture, generates an oversupply of labour in agriculture. The excess supply is directed to nonagriculture, but the ability of nonagriculture to absorb labour has to develop at a rather fast rate. The reason is that the more productive techniques in many industries are labour saving and are more profitable even in countries with low wages. Low agricultural wages is one outcome of this gap. That having been said, as we show in a companion paper, the same type of investments in education and health services that spur productivity gains on the farm also facilitate the flow of agricultural labour resources to other sectors (Butzer *et al.* 2003).

Addressing the problem of rural poverty remains a priority in these countries. While aggregate poverty rates have fallen, much of the reduction has been in urban poverty rates.[17] For example, in 1970, rural and urban poverty rates in Indonesia were comparable, but the reductions in urban poverty in the 1980s far exceeded any advances in the rural sector. In the Philippines, aggregate poverty rates have fallen, but remain high, especially in the rural sector.[18] Even in Thailand, where poverty rates have fallen dramatically since the early 1960s, 90 per cent of the poor live in rural areas (Zhang and Woicke 2002). The prevalence of rural poverty can be thought of in terms of inadequate transfer policies, but the more fundamental question is why poverty was not disappearing in light of the growth that was taking place. First, we should keep in mind that poverty is an outcome that is jointly determined among sectors and that the out-migration of labour discussed above contributed significantly to the reduction in poverty for each of the study countries.[19] In Thailand, the 'reduction in rural poverty can be attributed to increased farm household income … farm cash income deflated by CPI [consumer price index] declined after the 1980s, … after the [commodity] boom [of the 1970s], [Thai farmers] had to rely more on off-farm and non-farm income … urban areas have become more important to

[17] See Warr (2000) for actual data on poverty rates in Indonesia, Thailand, and the Philippines.

[18] Balisacan *et al.* (2002, p. 242) conclude 'that poverty reduction was relatively more responsive to economic growth after the mid-1980s than during the 1960s'.

[19] See Ravallion and Datt (1996) for a general discussion and Warr (2000) for a discussion that includes Indonesia, the Philippines and Thailand.

support the farm household economy' (Shigetomi 2004, p. 352). In the Philippines, the increased responsiveness of poverty rates to economic growth in the 1980s and 1990s can be attributed to the expansion of opportunities for non-farm income in rural areas.[20] Second, it is clear from the sources of growth discussion that the beneficiaries of growth in agriculture are determined by the ownership of resources. This issue is another aspect of the nature of the new technologies discussed above. Because the technologies are labour saving and the wages are kept relatively low, labour income is low. The wage rate did improve in some countries, but the big unknown is the average number of on-farm employment to which the daily wage rate is applied. In this situation, the welfare of landless labour is not improving, or may even be deteriorating.[21] However, the situation of land and capital owners is improving because the demand for the resources in their possession increases and with it their returns. Over and above this effect, the land owners have a natural advantage of being able to work more days on the farm and thereby increase their annual wage income even when they would be attributed the same daily wage rate. Aside from transfer programs done for humanitarian purposes, the alleviation of rural poverty depends largely on the development of employment opportunities outside agriculture. This can still be in the rural areas, but this is a separate issue related to the geography of development.

The terms of trade of agriculture play several roles, some of which are backstage. The flow of resources into agriculture depends on the relative profitability in agriculture, and this in turn depends on the real product price. Similarly, the choice of new techniques is sometimes justified only in a good price environment, which helps to offset initial setup costs, as well as risk. The real price is determined by the input prices and also by the prices of nonagricultural products. Such prices are determined in the economy at large, which generates the economic environment within which agriculture operates. Even though the macro environment is not part of agricultural policy, it can still hurt agriculture. Finally, world agricultural prices affect the domestic prices and thereby the profitability of agriculture. The challenge here is for the countries to form the economic environment

[20] Balisacan *et al.* (2004), based on Hayami and Kikuchi (2000).

[21] The importance of the ownership of resources is demonstrated in the Philippines, where there is a higher incidence of landlessness compared to other South-east Asian countries. 'Given a high inequality in the distribution of land holdings and the increasing proportion of landless population in rural areas, it is no surprise that even the substantial growth in aggregate agricultural production barely benefited the rural poor' (Balisacan *et al.* 2004, p. 241).

that will allow the countries to match the progress made in the rest of the world which has led to the declining prices.

7. Conclusions

The introduction of new high-yielding varieties of cereals in the 1960s, known as the green revolution dramatically changed the food supply in much of the world and especially in our three study countries. The three countries are close geographically, have similar climates and share many attributes. In some ways, the farming sectors in these economies reacted in similar ways to the newly available technology. However, there were crucial differences as well – some are the result of the natural resource base in each country and others the result of policy decisions. These differences contributed significantly to differences in growth among the countries.

The new varieties required fertilisers and irrigation for the realisation of their yield potential. Consequently, their appearance caused a jump in the demand for fertilisers and irrigated land. The expansion of irrigated land was gradual, subject to capital constraint and availability of adequate land. Meeting the expanded demand for fertilisers was done largely by the expansion of the domestic fertilisers industry, rather than by imports. The pace of expansion of irrigated land and of fertiliser supply affected to a large extent the growth rate of agricultural output. Because these factors were scarce, their shortage was reflected in their shadow prices. The shadow price of fertilisers exceeded the nominal or official price. This difference was absorbed by trade channels and thereby deprived farmers from benefiting fully from the new technology. Similarly, the shadow value of interest rates was for most of the period above ongoing real interest rates in international markets. The relative scarcity of these factors has an important effect on the empirical allocation of growth to the various determinants. It turns out that even though much of the growth was triggered by the new technology, factor accumulation has been the more important source of growth in agriculture. The contribution of the TFP varied between 10 per cent of the total growth in the Philippines to 44 per cent in Indonesia. TFP was more important in the 1960s and 1970s, following the introduction of the new crops, than in the later period when the pace of the progress depended mainly on the relaxation of the constraints on capital, fertilisers, and irrigated land.

The transition to the new technology has also benefited from investment in infrastructure (such as roads that helped to integrate remote areas with the market), education, and health. Differences in these factors contribute to the explanation of performance differences among countries and between episodes within countries. They are strongly correlated with the changes in the TFP.

By examining the shadow price of inputs we also find that capital and improved lands are more highly rewarded than labour. We attribute this to the fact that the new technologies are largely labour saving and capital intensive. The implication is that households that own land and capital participate directly in the benefits of growth, while the resource poor that remain in agriculture do not.

The future exploitation of these technologies will be limited by the amount of new land and irrigation that could be brought under cultivation. The growth implied by such an expansion is unlikely to be as dramatic as that observed in response to the green revolution. Major future changes in food supply will require changes in the available technology. Past experience indicates that the elimination of constraints to the implementation of the new technology will facilitate faster growth. The whole process is not unique to agriculture, and in a way, the present study serves as another illustration of the importance of the impact that the economic environment has on growth performance.

In summary, we find that factor accumulation played an important role in output growth and that accumulations from policy driven investments in human capital and public infrastructure were important sources of productivity gains. We suspect that because of limitations on land and water resources, such investments will become more important rather than less. We conclude that policies that ease constraints on factor markets and promote public investment in people and infrastructure provide the best opportunities for agricultural growth.

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Appendix: technical notes

I. The implemented technology

The available technology (AT) is defined as the set of all possible techniques of production, where a technique is represented by a production function: $AT = [F_j(X_j)]$, where $\boldsymbol{X} = \boldsymbol{V}, \boldsymbol{K}$ is the vector of all inputs. The optimisation problem calls for a choice of the techniques to be implemented and the level of inputs to be employed by each technique, subject to constraints on the inputs denoted by the vector $\boldsymbol{K}$ (Mundlak 1988):

$$\max_{V_j,K_j} L = \sum_j p_j F_j(V_j, K_j) - \sum_j \boldsymbol{w}' V_j + \lambda\left(K - \sum_j K_j\right) \quad (3)$$

The Kuhn-Tucker conditions lead to a solution where the optimal quantities, starred herewith, are written as functions of the state variables $\boldsymbol{s} = (\boldsymbol{K}, \boldsymbol{p}, \boldsymbol{w}, AT)$: $V_j^*(\boldsymbol{s})$, $K_j^*(\boldsymbol{s})$, $\lambda^*(\boldsymbol{s})$, and $Y_j^*(\boldsymbol{s}) = F_j(V_j^*, K_j^*)$. The implemented technology is the collection of all the techniques for which the optimal output is not zero, and therefore are actually implemented:

$$IT(\boldsymbol{s}) = \{F_j(V_j, K_j) : F_j(V_j^*, K_j^*) \neq 0, F_j \in AT\} \quad (4)$$

II. The empirical aggregate function

In practice, empirical production functions are defined in terms of outputs and inputs, which are aggregated over techniques. As such they are not identified by the state variables, because a change in the state variables affects the choice and intensity of techniques used and the inputs, and therefore does not trace a movement along a production function. What helps the identification are random deviations from the first order conditions affecting the inputs more than the choice of the techniques. An approximation to the aggregate function presented and discussed in the text is given by

$$\ln y = \Gamma(\boldsymbol{s}) + \boldsymbol{\beta}(\boldsymbol{s}, \boldsymbol{x}) \ln \boldsymbol{x} + u \quad (5)$$

Our maintained hypothesis is that when the state variables are properly introduced, the production function maintains constant returns to scale. Implicit in this assumption is that the property of increasing returns to scale, which has attracted attention in the published empirical growth literature, is the outcome of failing to allow for the impact of the state variables. We have not imposed constant returns to scale on the estimates, but have used it in order to derive the elasticity of labour.

III. Value added functions

Let the production function be

$$Y = F(\boldsymbol{V}, \boldsymbol{K}) \quad (6)$$

where Y is output, $\boldsymbol{V}$ is a vector of intermediate (variable) inputs, and $\boldsymbol{K}$ is a vector of constrained inputs. The constrained inputs are sometimes referred to as fixed inputs. The source of the constraints is not important for the present discussion. Let p be the price of output and $\boldsymbol{w}$ be the price vector of $\boldsymbol{V}$. The value-added function is defined as:

$$G(\boldsymbol{K}, p, \boldsymbol{w}) = \max_{y,v} (pY - \boldsymbol{w}'\boldsymbol{V}) \ s.t. \ Y \leq F(\boldsymbol{V}, \boldsymbol{K})$$

As shown by Bruno (1978), when the production function is separable in $\boldsymbol{V}$ and $\boldsymbol{K}$, in the sense that the marginal rate of substitution of the elements in

$\boldsymbol{K}$ are independent of $\boldsymbol{V}$ (e.g., Cobb-Douglas function), the value added function $G(\cdot)$ behaves as a production function in $\boldsymbol{K}$. Note that the prices of the output and of the intermediate inputs are arguments in $G(\cdot)$. We can refer to G as a restricted profit function.

The value added function assumes the maintaining of the competitive conditions. When those are met, by the envelope theorem, the introduction of an input to the function $G(\cdot)$ should have a zero coefficient. If this is not the case, the existence of the competitive conditions is questioned, as in the case of our discussion of fertilisers. The situation changes when we move to the case of the heterogeneous technology, as discussed above. The procedure followed allows us to approximate the function and to evaluate the shadow prices.