Optimizing Food Crop Diversification to Enhance the Rural Income Generated from the Agricultural Sector

Joko Mariyono.
Research Student, Crawford School of Economics and Government
The Australian National University
J.G. Crawford Building #13, Ellery Crescent-ANU. Canberra 2601, Australia

Abstract

Agricultural product diversification is one way to increase rural income. The objective of this study is to analyze the levels of production of rice, soybeans and maize on whether or not the proportion of the production is optimal. This analysis is based on data of rice, soybeans and maize production in five regions of Java. A microeconomic production theory is employed and the combination of productions is tested stochastically. Data are obtained from the publications of the provincial statistical office. The results show that the combination of rice and soybeans provided a maximum income but the combinations of rice and maize and soybeans and maize did not. The income resulting from the diversification can still be escalated by reducing production of rice and increasing production of maize. Since there is no water constraint to increase maize production, the best possible way to increase rural income is to replace rice cultivated in the dry season with maize.

JEL Classification: Q-19; D-24

Keywords: agricultural diversification, stochastic optimization, and product transformation curve

Introduction

Agriculture plays an important role in rural economic development. This is because most rural people are poor (Bigsten, 1994) and their basic necessities are mostly met by agricultural production (Nielsen, 1998). In Indonesia, the agricultural sector is also important because it absorbs approximately 50% of employment and provides around 20 % of Indonesian GDP (Hill, 2000). Most Indonesian people staying in rural areas are poor (Djojohadikusumo, 1994), and around 82% of them work in the agricultural sector in rural areas (Soekartawi, 1996). Poverty issues, which always relate to agricultural and rural communities (Kasryno and Stepanek, 1985), are expected to be reduced by improving agricultural practices.

Agriculture, which mostly covers farming practices, is one of the potential endowments for some regions. As ‘farming is a risky business’ (Ikerd, 1999 p. 1), farmers face risks coming from natural and economic factors. They lack control of the weather, market and environment (Soekartawi, et al. 1986). The natural risks associated with climate changes and disasters are very difficult to control, whereas the economic risk related to changes in price commonly occurs and such risks are inevitable (Kohls and Uhl, 1990). Diversification of products is one way to reduce both natural and economic uncertainties.

In natural terms, the advantage of the diversification is an ‘… insurance against crop failure … when one of the crops in a combination is damaged … the other crops may compensate for the loss’ (Altieri, 1987 pp. 74-75). From an economic point of view, the ‘diversification also can protect the firm from the risk of price change and market losses for a single product’ (Kohls and Uhl, 1990 p. 209). Jaenicke and Drinkwater (1999 p. 170) state that ‘economic comparisons of alternative and conventional systems generally show that alternative practices can be competitive if there is a substantial input-cost savings [and] a reduction in revenue risk through output diversification’. It has been highlighted that successful diversification is one of the triggers in the commercialization of agriculture in Asia (Schuh and Barghouti, 1988; Timmer, 1992).

If producers aim for the maximum feasible profit, however, it is important to take into account the right proportion of production in multi farming. Implicitly, if the cost of production is held constant, the maximum revenue leads to profit maximization. The combination of productions leading to maximum profit is actually influenced by the implemented technology and the prices of commodities. Determining optimal productions of multi products has been frequently conducted by employing a deterministic method, namely linear programming (Soekartawi, 1995). This method is able to find the optimal production deterministically. But, this method is very rigid since linear programming is deterministic, and it is consequently influenced by extreme observations (Greene, 1993). If prices of products are relatively stable over time, it is useful to apply such method.

In reality, there are fluctuations in market price because of seasonal and cyclical phenomena (Salvatore 1996). In the agricultural sector, 'numerous conditions contribute to agricultural price instability' (Kohls and Uhl, 1990 p. 169). Consequently, agricultural prices rise and fall within the year. Producers need to adjust the level of production according to changes in prices.

A stochastic (econometric) method is capable of coping with the rigidity of linear programming by incorporating an error structure (Greene, 1993). The stochastic method that comes across the optimal proportion of production will provide better findings of an optimal diversification. For that reason, this study has been carried out to measure whether or not the combination of productions is optimal by employing the approach of stochastic optimization.

This outcome is expected to provide a significant contribution for policy makers in order to escalate the regional income of the agricultural sector. Enhancing regional income from agricultural sectors is expected to be capable of triggering rural development since agricultural practices are mostly run in rural areas.

Theoretical framework

On the subject of the relationship between two commodities produced with the same resources, this study utilizes an economy of scope as a fundamental theory explained by Pindyck and Rubinfeld (1998). The centre to the theory is the product transformation curve describing 'the different combinations of two outputs that can be produced with a fixed amount of production inputs' (Pindyck and Rubinfeld, 1998 p.228). The 'product transformation curves are concave to the origin because the firm's production resources are not perfectly adaptable in (i.e., cannot be perfectly transferred between) the production of products …' (Salvatore, 1996 p. 460). It is therefore understandable that '…the joint output of a single firm is greater than the output that could be achieved by two different firms each producing a single product…' (Pindyck and Rubinfeld, 1998 p. 227).

Let Y_1 and Y_2 be rice and soybeans produced in the same resource represented by total production costs, C. The relationship between both products therefore can be mathematically expressed in an implicit function as:

$$C - \Omega(Y_1, Y_2) = 0$$
(1)

where $W(\cdot)$ is a continued and twice differentiable function that satisfies the following conditions:

$$\partial C / \partial Y_i > 0 \text{ for i= 1,2}$$
(A:1)

$$\partial Y_2 / \partial Y_1 \big|_{\bar{C}} < 0 \quad \text{and} \quad \partial^2 Y_2 / \partial Y_2^2 \big|_{\bar{C}} < 0$$
(A:2)

$$\lim_{Y_1 \to 0} \partial Y_2 / \partial Y_1 = 0 \quad \text{and} \quad \lim_{Y_2 \to 0} \partial Y_2 / \partial Y_1 = \infty$$
(A:3)

Conditions show that an increase in *C* results from increases in levels of Y_1 and Y_2; holding *C* constant, an increase in Y_1 leads to a decrease in Y_2 and vice versa; when Y_1 is zero, a tangency point at Y_1=0 is horizontal; and when Y_2 is zero, a tangency point at Y_2=0 is vertical. The condition of (A:2) means that the product transformation curve is strictly concave and monotonically decreasing. The condition of (A:3) guarantees a unique solution when the products have a market price. The product transformation curve is expressed in Figure 1.

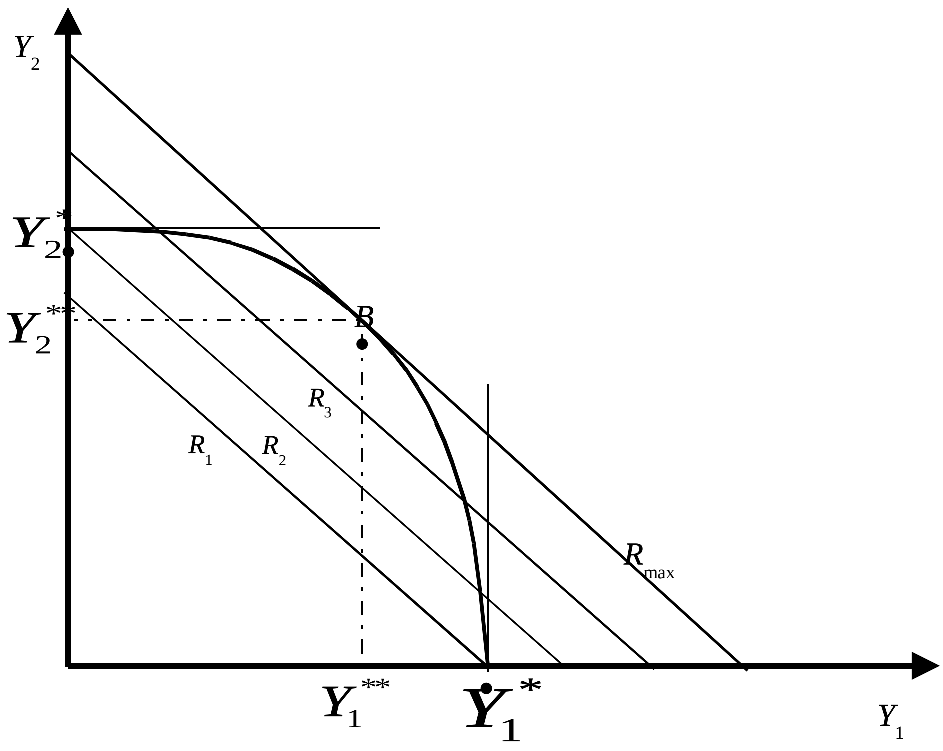

Figure 1. Maximizing revenue in diversification

Figure 1 shows a constant level of production costs, *C,* used to produce Y_1 and Y_2. Let *R* be revenue attained from the productions under given a market price of Y_1, P_1 and a market price of Y_2, P_2. When the cost is used to produce a single output, R_1 represents a revenue resulting from Y_1^*; and R_2 represents a revenue resulting from Y_2^*. But, when the cost is used to produce multi outputs, R_3 represents a revenue resulting from Y_1 and Y_2 as a joint production. If this is the case, the revenue resulting from the joint production, R_3, is greater than that of the single product, R_1 or R_2 at the same prevailing market prices P_1 and P_2. However, R_3 is not the maximum revenue. The maximum one is $R_{max.}$ It is reached at point *B* with the level of the joint production at $\left(Y_1^{**}, Y_2^{**}\right)$, that is, when the marginal rate of product transformation (MRPT) — the quantity of product Y_2 that must be given up in order to get one unit of product Y_1 (Pindyck and Rubinfeld, 1998) — is equal to the slope of the maximum revenue R_{max}. The producers maximizing revenue (*R*) subject to a cost constraint *C*, is formulated as:

$$\text{Max. } R = P_1 \cdot Y_1 + P_2 \cdot Y_2 \quad \text{subject to} \quad C - \Omega(Y_1, Y_2) = 0 \qquad (2)$$

The Lagrangian method postulates that the objective function of the revenue is formulated as:

$$\underset{Y_1, Y_2}{Max} \Re = P_1 \cdot Y_1 + P_2 \cdot Y_2 - l\left(C - \Omega(Y_1, Y_2)\right) \qquad (3)$$

The first order necessary condition for the maximization is:

$$\frac{P_1}{P_2} = -\frac{\partial Y_2}{\partial Y_1} \qquad (4)$$

It indicates that the optimum combination of each production leading to the maximum revenue will be reached when the negative MRPT is equal to the price ratio. [1]

Material and method

This study takes place in five districts in Java, namely: Bantul, Gunung Kidul, Kulon Progo, Sleman and a municipal area. Rice, soybeans and maize were chosen as the object because of major commodities grown as mixed cropping at the same time called an intercropping system, and planted as mixed cropping in a different time called a sequential cropping in one year.

This study analyses secondary cross-section and time-series data. The analysis is called a panel regression (Johnston and Di'Nardo, 1997). The data comprise five districts and ab eleven-year period 1989-1999. Data were collected from a series of regional figures published by the centre for statistical offices (BPS). The data consist of annual productions of rice, soybeans and maize (tons), total production costs spent in three commodities (million Rp) and average annual prices of rice, soybeans and maize (Rp per kg). The summary statistics for variables used in this study is given in Table 1 and Table 2. Note that the standard deviation of each corresponding variable is relatively high. This means that there is a variation in each variable across region and time. The variation is expected to provide a good estimation of the product transformation.

The first step of this analysis is to formulate the curve appropriately. Mariyono and Agustin (2006) using a quadratic form show empirically that the product transformation between rice and soybeans cultivated on the same land is strictly concave and monotonically decreasing. But the quadratic form does

[1] Because of the price ratio, there is no need to deflate both prices with any price index.

not meet the condition of (A:3), and consequently the unique solution for an optimal condition is not always the case, and a corner solution is the feasible case. An elliptical formula is one of the suitable forms that meets such condition of (A:3). Mariyono (2005) uses the formula to model a product transformation of an integrated farming system. By taking a position at the first quadrant where each variable is positive, the elliptical curve can be formulated mathematically as:

$$C = b_0 + b_1 Y_1^2 + b_2 Y_2^2 \qquad (5)$$

where C is total cost, Y_1 is product one, Y_2 is product two, and b_0, b_1, b_2 are coefficient to be estimated.

The next step to do is to calculate the value of *MRPT*. To simplify the derivation of MRPT, the estimated function is then converted into an implicit function, such that:

$$C - \left(b_0 + b_1 Y_1^2 + b_2 Y_2^2\right) = 0 \qquad (6)$$

The MRPT can be calculated from the implicit function (Chiang 1984), that is:

$$-MRPT = -\frac{\partial Y_2}{\partial Y_1} = \frac{F_1}{F_2} = \frac{b_1 Y_1}{b_2 Y_2} \qquad (7)$$

We can see that the condition of (A:3) is satisfied. When Y_2 is zero, the *MRPT* will be infinity. Conversely, when Y_1 is zero, the *MRPT* will be zero. The obtained *MRPT* is then assessed on whether or not the value evaluated at the average level of both products is equal to the price ratio. The test is conducted by the following formulations:

$$\frac{b_1 Y_1}{b_2 Y_2} = k_i \frac{P_1}{P_2} \Leftrightarrow \frac{b_1 Y_1 / b_2 Y_2}{P_1 / P_2} = k_i \qquad (8)$$

Equation (8) implies that if *MRPT* is equal to P_1/P_2, the value of k_i must be statistically equal to unity. The test of hypothesis follows the procedures of one-sample *t*-test explained by Newbold (1995). The two-tail significance test is formulated as follow.

Null hypothesis (H_0): $k_i - 1 = 0$

Alternative hypothesis (H_1): $k_i - 1 \neq 0$

The H_0 will be rejected if the value of two-tail t-ratio is greater than that of t-table. If the H_0 is not rejected, this indicates that the combination of the products is optimal. Estimating the product transformation function and testing for hypotheses are conducted by running STATA, a statistical computer program.

Result and discussion

Since there are problems of heteroskedasticity between panel and autocorrelation within panel, the product transformation is estimated using panel generalized least square to account for such problems (Greene, 2003). Table 3 shows the implicit functions of product transformation obtained from the estimation[2]. Overall, the estimates of product transformation function are highly significant. We can see that product transformation between rice and

[2] The objective is to find the best combinations of rice-soybean and rice-maize. The reasons are that rice is the main commodity always grown in the wet season, and soybean and maize are usually grown in the dry season after rice. It is less likely to grow soybean and maize in the wet season. In many cases, farmers cultivate either soybean or maize after rice. Combining three commodities in one equation is technically not reasonable. The estimated product transformation between soybean and maize is additional supporting information.

soybeans, and between rice and maize are strictly concave and monotonically decreasing. This means that maximizing revenue can be satisfied. But the product transformation between maize and soybeans is convex and monotonically increasing. This indicates that there is no trade off between maize and soybeans production. Consequently, the maximum revenue does not exist because an increase in maize production does not immediately mean a decrease in soybeans production, and vice versa. Both productions of maize and soybeans can be increased simultaneously. Biologically, combining soybeans with maize can increase production of both. This is due biologically to the ability of soybeans to fixate nitrogen from the air (Luther 1993, and both plants grow in a similar agro-ecosystem.

The concavity of the functions indicates that the degree of economies of scope in producing rice and soybeans, and rice and maize exists. In other words, the combination of rice and soybeans and rice and maize jointly produced using the same resource is technically higher than that of rice, soybeans or maize produced separately. However, identifying the optimality of the joint production needs to take into account the prevailing market prices of both commodities.

Table 4 shows the result of testing for optimal combination of each product. For the case of rice and soybeans, the MRPT is -2.9583. The estimated MRPT suggests that around three tons of soybeans should be given up in order to increase a ton of rice. At the same time, the price of soybeans is three-fold that of rice. It is clear that the value of k_i is statistically not different from unity. It means that the value of negative MRPT is equal to the ratio prices of products, by which the required condition of maximum revenue (equation (8)) is satisfied. This implies that producing rice and soybeans has been economically efficient. The composition of rice and soybeans has resulted in maximum revenue.

For the case of rice and maize, the MRPT is -2.3886. The estimated MRPT suggests that around 2.4 tons of maize should be given up to increase a ton of rice. At the same time, the price of rice is two-fold that of maize. The value of k_i is statistically grater than unity. It means that the value of negative MRPT is not equal to the ratio prices of products, by which the required condition of maximum revenue (equation (8)) is not fulfilled. This is because the production of rice is too much. Reducing rice production and increasing maize production can still increase revenue generated from the joint production of rice and maize. Since the value of k_i is statistically greater than unity, the production of maize is economically too low compared with the optimal production at given the prevailing market prices. In other words, a portion of irrigated lands devoted for producing rice is too much. Based on such conditions, the level of rice production needs to be replaced with maize. Furthermore, it should be pointed out that converting rice-sown lands to maize-sown lands should be followed by transferring costs in rice to maize proportionately. The effort to increase maize by replacing rice is feasible because there is no irrigation constraint. Based on the estimated product transformation function, the optimal combination of rice and maize is a condition of which the proportion of rice and soybeans production is 3.3:1. The current proportion of rice and maize production is, on average, 16:1, in which rice is excessively produced. Expanding corn cultivation will have double impacts on increasing income because it will improve revenue from the combination with soybeans.

Conclusion

The local government needs to identify the performance of agricultural productions, which provide a significant contribution to regional income. Increasing the agricultural performance leads directly to rural development because agricultural practices are mostly located in rural areas. Rice, soybeans and maize productions that have been performed with mixed cropping methods for more than a decade are expected to provide high returns optimally. The combination of rice and soybeans production has provided maximum income, but the combination of rice and maize, and soybeans and maize have not. This is because the production of maize is too low, despite the fact that the production demonstrates degree of economies of scope, meaning that the level of output yielded in mixed cropping is physically higher than that in single cropping. It is not too difficult to improve the economic performance of the diversification by increasing production of maize and reducing production of rice because there is no water constraint. The most feasible way of improving rural income from the diversification is to reduce rice cultivation in the dry season. This is can be done by converting rice-sown land to maize-sown land and other resources used in rice cultivation to maize cultivation until the optimum condition is reached. The optimum condition will be the case when the proportion of production of rice and maize is around 3:1. It is also economically viable to cultivate soybeans and maize simultaneously, since technically both plants are not trade offs.

References

Altieri, M.A., 1987. Agroecology: The Scientific Basis of Alternative Agriculture. Westview Press, Boulder, 227 pp.

Bigsten, A., 1994. Kemiskinan, Ketimpangan dan Pembangunan. In: Gemmell, N. (Ed). Ilmu Ekonomi Pembangunan. LP3ES, Jakarta, pp. 195-246.

Chiang, A. C., 1984. Fundamental Methods of Mathematical Economics. McGraw-Hill Tokyo, 788 pp.

Djojohadikusumo, S., 1994. Dasar Teori Ekonomi Pertumbuhan dan Ekonomi Pembangunan. LP3ES, Jakarta, 190 pp.

Greene, W.H., 1993. 'The Econometric Approach to Efficiency Analysis', in: Fried, H.O.; Lovell, C.A.K. and Schmidt, S.S. (Eds.), The Measurement of Productive Efficiency: techniques and applications, Oxford University Press, Oxford, pp. 68-119.

Greene, W.H., 2003. Econometric Analysis. Prentice Hall, New Jersey, 1026 pp.

Hill, H., 2000. The Indonesian Economy. Cambridge University Press, Cambridge, 366 pp.

Ikerd, J, E., 1999. Environmental risks facing farmers. Presented at Tri-State Conference for Risk Management Education, Pocono Manor, Pennsylvania, March 5-6, 1999.

Jaenicke E.C. and Drinkwater, L. E., 1999. 'Sources of productivity growth during the transition to alternative cropping systems'. Agric. and Res. Econ. Rev., 28 (2), 169-181

Johnston, J. and Di'Nardo, J., 1997. Econometric Methods. The McGraw-Hill Co. Inc. New York, 531 pp.

Kasyrno, F. and Stepanek, J.F., 1985. Dinamika Pembangunan Pedesaan. Yayasan Obor, Jakarta.

Kohls, R.L. and Uhl, J.N., 1990. Marketing of Agricultural Products. MacMillan Publishing Co., New York, 612 pp.

Luther, G. C., 1993. An Agro-ecological Approach for Developing an Integrated Pest Management System for Soybeans in Eastern Java. Unpublished PhD. Dissertation, University of California, Berkeley.

Mariyono, J. and Agustin, N.K., 2006. 'Economic optimisation of rice and soybean production in Jogjakarta Province'. SOCA, Jurnal Sosial Ekonomi Pertanian dan Agribisnis, Vol. 6 (2), 152-155

Mariyono, J., 2005. 'Optimisation of agribusiness on integrated farming system in Jogjakarta: a stochastic approach'. EMPIRIKA, Jurnal Penelitian Ekonomi, Bisnis dan Pembangunan'. Vol. 18 (2), 134-146

Newbold, P., 1995. Statistics for Business and Economics. Prentice Hall, Englewood Cliffs New Jersey, 867 pp.

Nicholson, W., 2002. Microeconomic Theory: Basic principles and extensions. South-Western/Thomson Learning, 748 pp.

Nielsen, N. O., 1998. Management for agroecosystem health: the new paradigm for agriculture. Proceedings of the Annual Meeting of the Canadian Society of Animal Science, Vancouver.

Pindyck, R.S. and Rubinfeld, D.L. 1998. Microeconomics. Prentice Hall International, Inc. Upper Sadle River, New Jersey, 726 pp.

Salvatore, D., 1996. Managerial Economics in a Global Economy. McGraw-Hill, New York, 722 pp.

Schuh, G.E. and Barghouti, S. 1988. 'Agricultural diversification in Asia'. Fin. and Dev., 25(2): 41–44.

Soekartawi, 1995. Linear Programming: Teori dan Aplikasinya Khususnya dalam Bidang Pertanian. Rajawali Pres, Jakarta, 43 pp.

Soekartawi, 1996. Pembangunan Pertanian untuk Mengentas Kemiskinan. UI Press, Jakarta., 26 pp.

Soekartawi; Soehardjo, A.; Dillon, J.L., and Hardaker, B.J., 1986. Ilmu Usaha-tani dan Penelitian untuk Pengembangan Petani Kecil. UI Press, Jakarta, 210 pp.

Timmer, C.P. 1992. 'Agricultural Diversification in Asia: Lessons from the 1980s and Issues for the 1990s', In: Barghouti, S.; Garbus, L. and Umali, D.L. (eds.), 'Trends in Agricultural Diversification: Regional Perspectives', World Bank Technical Paper Number 180, The World Bank, Washington, DC.

Table1. Summary statistics for variables, by region

Region	Variable	Obs	Mean	SD	Min	Max
Bantul	Rice	11	156691.9	9193.368	135436	167945
	Maize	11	24061.3	4892.614	17703	32694
	Soybean	11	9265.0	1887.881	5328	11880
	Cost	11	1.71E+10	8.75E+09	8.49E+09	3.91E+10
Gunung Kidul	Rice	11	152735.0	7494.221	137562	167124
	Maize	11	95929.5	27039.87	42098	150847
	Soybean	11	55560.5	13290.69	34724	77284
	Cost	11	4.30E+10	2.10E+10	2.28E+10	9.58E+10
Kulon Progo	Rice	11	106578.5	10841.32	81997	121096
	Maize	11	17589.6	4979.687	6610	25232
	Soybean	11	4186.7	1333.33	2048	5658
	Cost	11	1.16E+10	5.60E+09	5.39E+09	2.48E+10
Sleman	Rice	11	282706.5	23003.92	235730	305329
	Maize	11	20700.9	5395.753	11958	31998
	Soybean	11	1555.1	458.9482	634	2183
	Cost	11	2.95E+10	1.34E+10	1.52E+10	6.22E+10
City	Rice	11	3276.5	658.2632	1845	3912
	Maize	11	80.5	42.54025	36	161
	Soybean	11	19.9	8.619217	7	33
	Cost	11	3.12E+08	9.60E+07	1.83E+08	5.15E+08

Note: Author's calculation

Table 2. Summary statistics for variables, by year

Year	Variable	Obs	Mean	SD	Min	Max
1989	Rice	5	141299.4	108895.6	3641	305329
	Maize	5	28730.0	38623.22	36	96692
	Soybean	5	14200.4	24195.13	29	57020
	Cost	5	1.06E+10	9.09E+09	1.83E+08	2.36E+10
1990	Rice	5	140206.6	104607.2	3566	293761
	Maize	5	27694.2	29684.65	161	78372
	Soybean	5	13432.4	20550.31	33	49561
	Cost	5	1.10E+10	8.94E+09	2.01E+08	2.28E+10
1991	Rice	5	143932.8	105302.9	3912	295651
	Maize	5	26974.6	28225.47	127	74731
	Soybean	5	9398.0	15311.63	23	36431
	Cost	5	1.29E+10	1.07E+10	2.37E+08	2.77E+10
1992	Rice	5	144161.0	105047.5	3750	295635
	Maize	5	43439.2	60858.67	43	150847
	Soybean	5	18398.8	33087.97	20	77284
	Cost	5	1.37E+10	1.05E+10	2.61E+08	2.67E+10
1993	Rice	5	140162.6	99457.96	3631	281853
	Maize	5	17350.2	16068.82	59	42098
	Soybean	5	10748.6	14127.62	20	34724
	Cost	5	1.59E+10	1.30E+10	2.68E+08	3.41E+10
1994	Rice	5	146666.4	107410.6	3656	301986
	Maize	5	35437.6	41003.24	43	105971
	Soybean	5	12928.0	19732.21	29	47505
	Cost	5	1.97E+10	1.59E+10	3.38E+08	4.16E+10
1995	Rice	5	140167.4	99240.69	3710	276335
	Maize	5	37552.2	42073.26	66	110070
	Soybean	5	13960.6	22789.27	20	54070
	Cost	5	2.16E+10	1.79E+10	4.00E+08	4.63E+10
1996	Rice	5	145720.6	99826.41	3090	281087
	Maize	5	32141.4	31682.2	61	84786
	Soybean	5	15923.0	28279.73	7	66082
	Cost	5	2.27E+10	1.83E+10	3.40E+08	4.78E+10
1997	Rice	5	147857.2	106151.1	2828	297998
	Maize	5	36106.8	40046.69	128	104400
	Soybean	5	17224.0	29307.11	19	69145
	Cost	5	2.43E+10	1.98E+10	3.32E+08	5.16E+10
1998	Rice	5	131722.2	89115.43	2413	244407
	Maize	5	33444.0	42112.17	55	107114
	Soybean	5	12926.8	23182.22	7	54188
	Cost	5	2.67E+10	2.08E+10	3.57E+08	5.49E+10
1999	Rice	5	122478.6	87182.93	1845	235730
	Maize	5	29525.6	40130.25	107	100143
	Soybean	5	16151.2	27629.54	12	65155
	Cost	5	4.45E+10	3.64E+10	5.15E+08	9.58E+10

Note: rice, maize and soybean are measured in tons; cost is measured in million Rp

Table 3. Implicit function of product transformation

Variables	Rice-Soybean		Rice-Maize		Soybean-Maize	
	Coef.	z-ratio	Coef.	z-ratio	Coef.	z-ratio
Cost	-1		-1		-1	
Constant	5.66E+09	8.96**	5.76E+09	7.47**	1.34E+10	10.78**
$Rice^2$	0.2005	7.11**	0.1759	5.98**		
$Soybean^2$	6.0711	5.67**			8.8689	4.36**
$Maize^2$			1.2119	3.16[a]	-1.0049	-1.71*
Log likelihood		-1284.57		-1287.68		-1291.133
Wald-test		60.36**		36.69**		36.54**
Observation		55		55		55

Note: ***P*<0.01; **P*<0.1

Table 4. The average value of MRPT and the test of optimal production

	$\partial Y_2 / \partial Y_1$	Price ratio (P_1/P_2)	$k_i = \frac{-MRPT}{P_1/P_2}$	Average k_i-1	two-tailed t-value
Rice-Soybean	-2.9583	2.8098	1.0202	0.0202	0.1259
Rice-Maize	-2.3886	0.4864	4.5047	3.5047	4.6903**
Soybean-Maize	2.9183	0.1688	-16.5063	-17.5063	-9.5021**

Note: ***P*<0.01