Research and agricultural productivity in Indonesia[*]

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Growth of total factor productivity has contributed 41 per cent of output growth in Indonesian agriculture since 1975. This study examines the extent to which publicly funded agricultural research within Indonesia has contributed to this productivity growth, while allowing for other possible determinants, including spillovers from international agricultural research, extension, weather changes, and government trade and subsidy policy. The econometric results imply a real annual rate of return to a marginal increase in Indonesian agricultural research expenditure of 27 per cent. Government-financed agricultural research explains 56 per cent of the observed increase in total factor productivity since 1975.

Introduction and summary

In Indonesia as elsewhere there is genuine concern about future food security. It is feared that rising population, increasing food demand per person and increasing demand for biofuels, tightening supplies of natural resources, and climate change may raise global and domestic food prices. Rising food prices can be expected to increase poverty incidence in Indonesia (Warr and Yusuf 2009). Raising agricultural productivity is thus important for maintaining food security and mitigating the danger of rising food prices while at the same time improving the living standards of Indonesia's poor people.

Estimates of total factor productivity (TFP) from Fuglie (2010) imply that over the three decades ending in 2006 growth of TFP accounted for 41% of real value-added growth in Indonesian agriculture. Growth of value-added in agriculture accounted for 16% of real GDP growth over the same period. Agricultural TFP growth therefore explains 6.6% of total real GDP growth. Nevertheless, the growth rate of agricultural TFP has slowed.[1] Refocusing attention on what determines TFP in Indonesian agriculture is thus of great policy interest.

[*]Contributed paper to Australian Agricultural and Resource Economics Society, 56th conference, Fremantle, February 7 to 10, 2012. Research assistance from Hemantha Jalath Ekanayake, initial funding from the Australian Centre for International Agricultural Research (ACIAR), and assistance with data from the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS) and Keith O. Fuglie are gratefully acknowledged.

[1] This point is confirmed by regressing Fuglie's TFP index, cited above, on time and time-squared. The coefficient on time is positive and significant and the coefficient on time-squared is negative and significant.

This study examines the extent to which government-sponsored agricultural research within Indonesia, measured as the real purchasing power of research expenditures, contributes to the enhancement of agricultural productivity growth. The statistical analysis allows for other possible determinants of agricultural productivity growth, including international agricultural research, agricultural extension, weather changes, changes in the composition of agricultural output and epidemics. The data used relate to the years 1974 to 2006. The econometric methodology is based on the error correction procedure of Hendry (1995), designed for the analysis of time series data.

The results show that expenditure on agricultural research has a significant effect on total factor productivity in Indonesian agricultural production. The long-run impact elasticity (per cent change in total factor productivity from a 1 per cent increased in research expenditure) is estimated at 0.20. The results also confirm that international agricultural research has significant spillover effects on Indonesian productivity growth.

Based on these econometric results, a projection is made of the impact on total factor productivity within Indonesian agriculture of a hypothetical, one year only, marginal increase in agricultural research expenditure in the year 1975. Impacts on the change in the real value of Indonesian agricultural output over time are estimated from this analysis. A real rate of return of 27% from this marginal increase in investment in agricultural research is estimated from these results. Finally, projections based on the above results further imply that expenditure on agricultural research explains 56 per cent of the productivity growth in Indonesian agriculture that occurred between 1975 and 2006.It is concluded that Indonesia has under-invested seriously in this form of public expenditure.

2. Analytical framework

The primary concept is a production function that distinguishes between, first, conventional farm-level inputs, *X*, such as labor, land and capital, and second, inputs and other determinants of output that operate beyond the farm-level, *Z*. The latter include research, extension, weather and disease outbreaks. Studies of total factor productivity in agriculture normally take account only of the farm-level inputs, which are measured in farm-level surveys. The contribution of the beyond-farm inputs, *Z*, is thus assigned to an unexplained residual (Solow 1957, Jorgenson and Griliches 1967, Jorgenson 1995).The interest in this study is in explaining that residual.

Let the production function at time *t*, be

$$Q_t = h(X_t, Z_t), \tag{1}$$

where Q denotes value-added in agriculture (the value of total output minus the value of intermediate inputs such as fertilizer, fuel and chemical inputs). It is convenient for exposition, but not essential, to assume that the function h is multiplicatively separable between conventional and non-conventional inputs, giving

$$h(X_t, Z_t) = f(X_t)g(Z_t) \tag{2}$$

By definition, TFP is an index of aggregate output (value-added) relative to an index of aggregate conventional inputs. It is therefore a function of the levels of non-conventional inputs:

$$TFP_t = Q_t / f(X_t) = g(Z_t). \tag{3}$$

Our focus in this study is on the content of the function $g(Z_t)$. Assuming $h(X_t, Z_t)$to be differentiable, it is familiar thatthe growth rate of TFP (TFPG) is given by

$$TFPG_t = q_t - \sum_{i=1}^{I} \varepsilon_t^i x_t^i = \sum_{j=1}^{J} \eta_t^j z_t^j \tag{4}$$

where q_t, x_t^i and z_t^j denote the proportional rates of change of Q_t, X_t^i and Z_t^j, respectively. Thus, $q_t = (dQ_t / dt) / Q_t$.[2] The parameters $\varepsilon_t^i = h_{xi} X_t^i / Q_t$ and $\eta_t^j = h_{Zj} Z_t^j / Q_t$(which may or may not be constant over time) denote the elasticities of output with respect to the inputs X_t^i and Z_t^j, respectively.

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[2]Since differentiation is applicable only to continuous variables, the growth rate terms in the above equations refer to an instantaneous rate of change. However, in practice, discrete data, especially annual data, are normally used in empirical work. Hence, the discrete annual data can be applied to approximate equation (5) by taking the average of factor shares at two consecutive periods (Oguchi, 2004).

Equivalently, the change in TFP is measured as the residual part of the movement in output that is left unexplained by the growth of conventional factor inputs. As is well known, if the function $f(X_t)$ is linearly homogeneous (constant returns to scale in conventional inputs at the farm level), and these conventional factors are paid according to their marginal value products, then the elasticity parameters ε_t^i are equal to the corresponding factor cost shares at time t and these factor cost shares will sum to unity across the I conventional factor inputs.

The hypothesized determinants of TFP ï the function $g(Z_t)$ï include the factors affecting the productivity of conventional inputs, including agricultural research, both domestic and foreign,[3] as well as extension services, exogenous economic events and weather.[4] Research takes time to impact on productivity, so lags must be allowed for, as discussed below. Other explanatory variables are explored in accordance with their potential connections with TFP.

In stylized form, the model is (with expected signs in parentheses):

$$TFP = g(GER, IER, GEE, TRA, RF, FS, D^c), \tag{5}$$

where TFP = total factor productivity in agriculture,

GER (+) = real government expenditure on agricultural research,

IER (+) = realinternational expenditure on agricultural research,

GEE (+) = real government expenditure on agricultural extension,

TRA (+) = total rate of government assistance to agriculture,

RF (+) =rainfall,

FS (ï) =share of food crops in agricultural output,

D^c = case-specific dummy variables comprising:

D^1 (+) = the abnormally favorable climatic and pest control circumstances of 1980,

D^2 (ï) = the disruptive effects of the Asian Financial Crisis of 1997 and 1998.

[3]Spillovers from international research are potentially important sources of productivity growth, but they have typically been ignored in the literature on the impact of agricultural research, resulting in a possible omitted variable bias (Alston et al., 1998, Alston, 2002, Fuglie and Heisey, 2007).

[4]Evenson (2001), Alston et al. (1998) and Evenson and Pray (1991) argue for the inclusion of case-specific and natural factors such as major weather events, environmental degradation, epidemics and natural disasters.

3. Explanatory variables and data sources

Total factor productivity (TFP): uses data reported and explained in Fuglie (2010), drawing upon earlier quantitative work by van der Eng (1996).[5]Fuglie reports detailed adjustment for changes in the quality of labor inputs, through changes in the education and gender of farm labor and changes in the quality of land inputs, through changes in the extent of irrigation.[6]

Government expenditure on agricultural research (GER): uses data provided by the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Ministry of Agriculture, Government of Indonesia, Bogor. These data are expressed in nominal local currency (Rupiah), current prices, and include government expenditures financed by foreign sources. They were deflated to a constant price series using the Indonesian Wholesale Price Index provided by the Central Bureau of Statistics, Jakarta. The resulting flow series was then converted to a stock, using the perpetual inventory method. Let the flow in each year, measured in constant prices, be f_t. The stock in year *t* is thus $s_t = f_t + s_{t-1}/(1+d)$, where *d* is the rate of depreciation, assumed to be 5%.

International expenditure on agricultural research (IER: uses data on total research expenditure by the three major centres under the CGIAR with close collaboration with Indonesia: IRRI, CIMMYT and CIAT. The data were obtained in US dollars and deflated using the US Wholesale Price Index.The data were then converted to stock form using the method described under GER above.

Government expenditure on agricultural extension (GEE): data, deflator and conversion to stock form were as described under GER above.

Total rate of government assistance to agriculture(TRA): measured as the Direct Rate of Assistance (DRA) to agriculture minus the DRA to manufacturing, estimated and

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[5]Fuglie reports estimates of output (value-added), factor inputs and TFP, from 1961 to 2006, each series indexed to 100 in 1961. The TFP series was re-indexed to 1961 = 100 in the present study to maintain the identity $V_t = F_t T_t$, where V_t, F_t and $T_t$are the levels of total output (value-added), total factor inputs and total factor productivity, respectively, each in year *t*.

[6]Since changes in land quality through irrigation is incorporated into the measurement of land inputs, it should presumably not be among the residual inputs to be included in the vector *Z.* This assumption is tested and confirmed below.

described in Fane and Warr (2009). The data reported in that study were also used by Rada, Buccola and Fuglie (2011), who claim positive effects on agricultural productivity.

Rainfall (RF): data on Indonesian rainfall were obtained from the online data set accompanying Dell, Jones and Olken (2008).

Share of food crops in total output (FS): data used were the share of food crops in total output by value, reported by the Central Bureau of Statistics, Jakarta. Over the three decades of the data the share of annual food crops in total output declined while the share of perennial estate crops ï coffee, tea, palm oil and rubber ï increased. Government research is more concentrated on estate crops, so its effect on agricultural productivity could have risen as the output share of estate crops increased.

***Dummy variables (D)*:** the dummy variables relate to: 1980, when agricultural output suddenly surged, due to favorable climatic and pest control reasons; and 1997-98, when all sectors of the Indonesian economy were disrupted by the Asian Financial Crisis. Agriculture was affected negatively, but less than most other sectors.

4. Statistical methodology

The statistical relationship between research and productivity involves important issues of research lags. In dealing with lags in the impact of research the usual practice has been to impose arbitrary restrictions on the lag structure such as the second-degree polynomial distributed lag (bell-shaped lag structure). Imposing a lag structure that is too short or is otherwise inappropriate tends to bias upwardly the estimated research impact and associated rate of return (Alston et al., 1998a, Alston et al., 2000).

The error correction mechanism (ECM),developed by Hendry (1995) and others, offers an improved method to estimate the long-run dynamic relationships among time series economic variables (Makki et al., 1999) and separating these relationships from short-run dynamics. The ECM thus allows for both short-term and long-term relationships among variables and does not impose any restrictive form of lags. Under the ECM, the long-run relationship is embedded within a sufficiently detailed dynamic specification, including both lagged dependent and independent variables, which helps minimize the possibility of estimating a spurious regression.

A further advantage of the ECM is that it does not require that the variables under consideration have the same order of integration. Table 1 shows that the variables used in this study are a mixture of stationary series (I(0)) and non-stationary series integrated of order 1 (I(1)). The I(1) variables are Total Factor Productivity (*TFP*), Government trade and tax interventions (*TRA*), and Food crop share (*FS*). All others are I(0). The ECM approach minimizes the possibility of estimating spurious relationships in such circumstances, retaining long-run information without arbitrarily restricting the lag structure (Hendry, 1995). The ECM also provides estimates with valid t-statistics even in the presence of endogenous explanatory variables (Inder, 1993).

The estimation procedure begins with an autoregressive distributed lag (ADL) specification of an appropriate lag order.

$$Y_t = \alpha + \sum_{i=1}^{m} A_i Y_{t-i} + \sum_{j=1}^{k}\sum_{h=0}^{n} B_{hj} Z_{j,t-h} + \mu_t \qquad (6)$$

where α is a constant, Y_t is the endogenous variable at time *t*, $Z_{j,t}$ is the *j*th explanatory variable at time *t*, and A_i and B_{hj} are parameters. The general ADL allows the initial lag length on all variables at two periods, except for the research variable where the lag length extends to four periods. Subtracting Y_{t-1} from both sides yields the explanatory variables in terms of differences, representing the short-run multipliers, and the lagged levels of both the dependent and explanatory variables, capturing the long-run multipliers of the system.

$$\Delta Y_t = \alpha + \sum_{i=1}^{m-1} A_i^* \Delta Y_{t-1} + \sum_{j=1}^{k}\sum_{h=0}^{n-1} B_{hj}^* \Delta Z_{j,t-h} + C_0 Y_{t-m} + \sum_{j=1}^{k} C_j Z_{j,t-n} + \mu_t \qquad (7)$$

where $A_i^* = -[I - \sum_{i=1}^{m-1} A_i]$, $B_{hj}^* = \sum_{h=0}^{n-1} B_{hj}$, $C_0 = -\left[I - \sum_{i=1}^{m} A_i\right]$, $C_j = \left[\sum_{h=0}^{n-1} B_{hj}\right]$, I is the identity matrix and the long-run multipliers of the system are given by $C_0^{-1} C_j$.

Equation (7) forms the basis for the error correction mechanism (ECM) representation of the model (Wickens and Breusch 1988, Banerjee *et al.* 1993, Hendry 1995).). The ECM can be estimated by OLS and the short- and long-run parameters can be separately identified. Equation (7) is the ómaintained hypothesisô for specification search. The full model is then ‘tested down’ by dropping statistically insignificant lag terms using the standard testing procedure to obtain a parsimonious ECM. The final preferred model is required to satisfy standard diagnostic tests, including the Augmented Dickey-Fuller (ADF) test for residual stationarity and the Breush-Godfrey LM test for serial correlation in the regression residual.

5. Regression results and the rate of return to research

The regression results are reported in Table 2.[7] Applying the Hendry general-to-specific approach, variables in Model 1 that were highly insignificant were eliminated to obtain Model 2, and the same again, to obtain Model 3.[8] All remaining variables are significant at the 5% level at least, and the overall regression is highly significant according to the *F*-test. Table 3 reports test results on the residuals in Model 3. The residuals are stationary and the estimated model has no significant serial correlation.[9] The surviving long-run variables in Model 3 are government expenditure on research (*GER*) and international expenditure on research (*IER*), which are significant at the 1% and 5% levels, respectively.[10] All other variables were insignificant, including the variable for government assistance to agriculture (*TRA*).[11] The long-run elasticities of *TFP* with respect to *GER* and *IER* are given by $-\beta/\alpha$ = 0.20 and $-\gamma/\alpha$ = 0.22, respectively, where α, β and γ are the estimated coefficients on $\ln TFP_{-1}$, $\ln GER_{-1}$ and $\ln IER_{-1}$.

In short, both domestic and international expenditure on agricultural research contribute positively and significantly to total factor productivity in Indonesia. These findings are consistent with studies of many countries, which find that agricultural research is an

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[7] All data used in the regressions and their sources are provided in Data Appendix A.

[8] As discussed above, the expansion of irrigated area was allowed for in Fuglie’s construction of the quality-adjusted land input variable. It should therefore not be a significant determinant of residual TFP. This was confirmed by adding the percentage of land area that is irrigated as an explanatory variable in Model 1. The variable was insignificant and did not materially affect the significance of the other variables. This was also true of the infrastructure variable road length, not reported in Table 2.

[9] The null hypothesis of the augmented Dicky-Fuller test is that the residuals have a unit root. This hypothesis is rejected at better than 99% level of confidence. The null hypothesis in the Breusch-Godfrey test for serial correlation is that there is no serial correlation in the residuals. This hypothesis is not rejected.

[10] Applying a similar methodology to data from Thailand, Suphannachart and Warr (2011) found that the flow of government research expenditure fitted the data more successfully than the stock. The opposite was foundwith the Indonesian data used in the present study.

[11] Rada, Buccola and Fuglie (2011) attribute considerable explanatory power to the nominal rate of assistance to agriculture. This variable, also reported in Fane and Warr (2009) was tried in place of the theoretically preferred total rate of assistance used in Models 1 and 2. It was insignificant in both cases.

important source of productivity- raising technical change (Evenson, 1993, Fuglie, 1999, Ruttan, 2002, Thirtle et al., 2003).The negative and highly significant intercept term is important. In the absence of the expansion of international research (*IER*) and government research (*GER*), total factor productivity would have declined substantially.

What is theinternal rate of return to a marginal increase in expenditure on agricultural research? This question is explored by means of the following experiment, based on the estimated econometric model reviewed above. A projection is made of the effect of a hypothetical 1 billion Rupiah increase in agricultural research in 1975 only, measured in 1974 prices, relative to its observed level in that year, with all other right hand side variables set at their observed levels. After 1975 the counterfactual level of research expenditure then reverts to its observed value in the data. The projected level of TFP arising from this simulation is then calculated for each year beginning in the following year,1976, and ending in 2006. This stream is then compared with the results of an identical projection, except that the hypothetical increase in agricultural research expenditure does not occur ï its value, along with the values of all other right-hand-side variables, remains at its level observed in the data. The difference between the levels of TFP in each yearunder these two projections is the estimated impact that the 1 billion Rupiah spending increase in 1975 hason the level of TFP in each subsequent year.

Recall that in the regression analysis agricultural research is measured as a stock, constructed from the raw flow data on expenditures, converted to constant price terms, using the perpetual inventory method. Let the flow in each year, measured in constant prices, be f_t, where t runs from 1975 to 2006. Now consider two time series of the flows of agricultural research in each year from 1975 onwards, as follows:

<u>Case 0</u>: The flow in each year is the same as the observed time series data, denoted f_t^0.

<u>Case 1</u>: The flow increases in 1975 by 1 billion Rupiah, measured in 1974 prices, relative to the observed time series data, but is the same as the observed data in all other years. Thus, measuring in billions of Rupiah in 1974 prices, $f_t^1 = f_t^0 + 1$ for $t = 1975$ and $f_t^1 = f_t^0$ for all other years.

Now consider the time series of the stock of agricultural research implied by these two cases, denoted s_t^0 and s_t^1, respectively, again measured in billions of Rupiah at constant 1974 prices. It is readily shown that the stock in year *t,* where *t* = 1975,1976,é ,2006 is given by

$$s_t = s_{1974} /(1+d)^{t-1974} + \sum_{\tau=1975}^{t} f_\tau /(1+d)^{t-\tau} . \qquad (8)$$

The difference between the two stock series in year *t* is therefore

$$s_t^1 - s_t^0 = 1/(1+d)^{t-1975} . \qquad (9)$$

To illustrate, in 1975 the difference is 1, the amount of the shock. In 1976 the difference is $1/(1+d) = 1/1.05$, where d = 0.05 is the rate of depreciation, roughly 0.953. In 1977 it is $1/(1.05)^2$, roughly 0.907 and 1978 it is $1/(1.05)^3$ billion, roughly 0.864, and so forth. That is, the difference between the two streams of the *stock* of agricultural research decays with depreciation of the hypothetical shock of size 1 occurring in 1975.

The two streams of stocks, s_t^0 and s_t^1, have different implications for the levels of total factor productivity over the 1975 to 2006 period. The method used here for estimating the rate of return to the investment in 1975 uses the econometric results derived to project the two streams of total factor productivity that result from these two streams of the stock of agricultural research - arising with and without the 1975 increase in expenditure ï where the levels of other explanatory variables are the same in the two projections, equal to the observed levels in the data. Denote the twoprojected streams of *TFP*by $\hat{T}_t^0$ and $\hat{T}_t^1$, respectively. Recall that the econometric model, as estimated, implies that a change in the stock of GER in, say, year *t*-1affects the level of level of TFP beginning in year *t* and not the year *t*-1, because the dependent variable is $\Delta \ln TFP_t = \ln TFP_t - \ln TFP_{t-1}$ and the independent variables include $\ln GER_{t-1}$ but not $\ln GER_t$. The two streams $\hat{T}_t^0$ and $\hat{T}_t^1$ are thus the same in 1975 but differ in all subsequent years.[12]

Now consider the identity $V_t = F_t T_t$, where V_t, F_t and T_t denote the levels of total output (value-added), total factor inputs and total factor productivity, respectively, each in year *t*. The time series F_t^0 will denote the levels of factor input implied by the Fuglie data series on

[12] The difference between $\hat{T}_t^0$ and T_t^0 is the modelôs prediction error. We compare $\hat{T}_t^1$ with $\hat{T}_t^0$, rather than T_t^0, to avoid confounding the comparison with prediction error.

TFP, denoted T_t^0, indexed to 1 in 1961, and the official data on real value-added in agriculture, V_t^0 ,calculated as $F_t^0 = V_t^0 / T_t^0$.[13]The levels of value-added corresponding to the two projected series of TFP are thus $\hat{V}_t^0 = F_t^0 \hat{T}_t^0$ and $\hat{V}_t^1 = F_t^0 \hat{T}_t^1$, respectively, and the difference between them is the value in each year from 1976 onwards of the additional output made possible by the productivity-enhancing effect of the increased expenditure on research in 1975, given by the series $\hat{V}_t^1 - \hat{V}_t^0 = F_t^0(\hat{T}_t^1 - \hat{T}_t^0)$.

Figure 3 shows the estimated value of the stream of net economic benefits arising from the 1975 investment, all expressed in billions of Rupiah in constant 1974 prices.[14] In 1975 it is negative, -1 billion Rupiah, representing the cost of the investment, and in each subsequent year it is the positive value, $\hat{V}_t^1 - \hat{V}_t^0$. The internal rate of return (IRR) from this series of net benefits can be calculated as the rate of discount that leads the series to have zero net present value in 1975.This is the value of *r* such that

$$\sum_{t=1976}^{2006} \left[(\hat{V}_t^1 - \hat{V}_t^0)/(1+r)^{t-1975} \right] - 1 = 0. \qquad (10)$$

The resulting IRR was 27 per cent.

6. The contribution of research to TFP growth

To what extent does Indonesia's agricultural research explain the impressive growth of TFP? This question is addressed by using to estimatedstatistical model (Model 3) to project the level of TFP in each year from 1975 onwards under alternative counterfactual assumptions about the explanatory variables. The results are summarized in Figure 4.

Six series of agricultural value-added are shown, all in constant 1974 prices:
<u>Actual level</u>: the raw data.
<u>Level in 1975</u>: no growth of either factor inputs or TFP.

[13] The data series implied by these calculations are provided in Data Appendix B.

[14]All data used in these calculations and their sources are provided in Data Appendix B.

Factor growth: factor inputs increase as in the data, but no TFP growth.[15]
Projection A: factor inputs increase, TFP projected with IER and GER constant.
Projection B: factor inputs increase, TFP projected with IER as in the data, but GERconstant.
Projection C: factor inputs increase and TFP projected with IER and GER as in the data.

Projections A, B and Ceach draw upon the data in combination with Model 3, summarized in Table 2. The differences between these series are the estimated contributions of particular sources of output growth from 1975 to 2006, as follows:

> *Factor growth- Level in 1975* is the estimated contribution of factor input growth alone.
> *Projection A–Factor growth* is the estimated additional contribution of TFP growth due to explanatory factors other than international research and government research.
> *Projection B- Projection A* is the estimated additional contribution of TFP growth due to international research.
> *Projection C- Projection B* is the estimated additional contribution of TFP growth due to government research.
> *Actual VA - Projection C*is the prediction error in the model.

The sizes of these projected contributions to value-added growth from 1975 to 2006 are summarized in Table 4. Actual value-added in agriculture (in millions of Rupiah at constant 1974 prices) grew from 20,960 in 1975 to 66,396 in 2006, an increase of 45,436 (217 per cent). At constant TFPthe growth of factor inputswould explain 36.6 per cent of the observed expansion of output. But in the absence of either spillovers from international research or government-sponsored research, the level of TFP would have declined sufficiently (by 35.1 per cent) to negate almost all of the gain in output that factor growth made possible.[16]Spillovers from international research contributed 40.2 per cent of the growth of output, sufficient to eliminate the decline in TFP that would otherwise have occurred and government research contributed an additional55.9 per cent of the observed output growth.

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[15] Calculated as $V_t = F_t^0 \overline{T}_{1975}$, where F_t^0 is the level of factor inputs estimated above and $\overline{T}_{1975}$ is the level of *TFP* in 1975, held constant.

[16]Reflected by the large and negative intercept term in the estimated model (Table 2).

These results differ radically from thosereported in a recent, important paper by Rada, Buccola and Fuglie (2011) ï subsequently RBF. The RBF results attribute very little TFP growthto government research (p. 867):

> We find that agriculturally focused liberalization efforts and massive depreciation succeeded in lifting Indonesian farm technology growth. Yet government-sponsored research can take little credit for the improvement.

The RBF analysis uses data for 22 provinces in 5 regions of Indonesia. The provincial data are aggregated to the regional level and the statistical analysis then relates regional TFP growth to regional research, measured as numbers of research employees. Spillovers from international research are not mentioned. Spillovers between regions are ruled out(p. 873):

> Although regionally located institutes may, regardless of their location, have some national research mandate, we assume their programs are oriented toward local or at least regional agronomic conditions.

This assumption is summarized in Figure 5. Simplifying to two regions, each containing two provinces, RBF assume that research in each region affects productivity in the provinces contained in that region (solid lines) but has no spillover impact elsewhere (fainter lines). If this strong and undefended assumption is incorrect, the contribution of government-sponsored research will be understated, possibly explaining the difference in results between RBF and the present study.

7. Conclusions

The results of this study indicate significant underinvestment in agricultural research within Indonesia. Given the governmentøs objective of raising the level of Indonesiaøs food self-sufficiency, combined with rapid population growth, diminishing returns on traditional factor inputs, declining availability of arable land, fresh water supplies and other natural resources, concern over climate change and environmental degradation, along with high fuel and fertilizer prices, it is clear that agricultural research deserves a much higher policy priority within Indonesia than it has received in recent years.

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Table 1. Unit root tests

Variable	ADF statistic for level	ADF statistic for first difference	Order of integration
Total factor productivity	-2.724	-6.558***	I(1)
Govt. expenditure in research (stock)	-3.484*		I(0)
Govt. expenditure in extension (stock)	-11.44***		I(0)
Foreign research expenditure (stock)	3.324*		I(0)
TRA	-2.273	-7.556***	I(1)
Rainfall	-3.830**		I(0)
Food crop share	-2.891	-5.539***	I(1)

Note: Statistical significance at the 1, 5 and 10% levels is indicated by ***, *** and *, respectively.
Source: Authorǿs calculations.

Table 2: Estimation results (1975 to 2006)

	Model 1	**Model 2**	**Model 3**
Dependent variable: $\Delta \ln TFP_t$			
Independent variables:			
Constant	-1.4782	-1.1416***	-1.0555***
	(0.2616)	(0.0071)	(0.0007)
D^1	0.0438**	0.0533***	0.0531***
	(0.0473)	(0.0000)	(0.0000)
D^2	-0.0538**	-0441***	-0.0434***
	(0.0182)	(0.0084)	(0.0066)
$\ln TFP_{t-1}$	-0.5791***	-0.5086***	-0.4994***
	(0.0034)	(0.0009)	(0.0004)
$\ln GER_{t-1}$	0.1541**	0.1061***	0.0993***
	(0.0379)	(0.0038)	(0.0006)
$\Delta \ln GER_t$	0.0154		
	(0.8643)		
$\ln IER_{t-1}$	0.1646**	0.1176**	0.1122**
	(0.0304)	(0.0467)	(0.0365)
$\Delta \ln IER_t$	1.3384*	1.0069**	0.9353***
	(0.0759)	(0.0223)	(0.0082)
TRA_{t-1}	-0.0012*	-0.0001	
	(0.0973)	(0.7732)	
ΔTRA_t	-0.0004		
	(0.4705)		
$\ln GEE_{t-1}$	-0.0128		
	(0.9265)		
$\Delta \ln GEE_t$	0.2024		
	(0.4294)		
$\ln RF_{t-1}$	-0.0003		
	(0.8385)		
FS_{t-1}	0.2688		
	(0.5651)		
$\Delta \ln TFP_{t-1}$	0.0558		
	(0.7333)		
Long-run elasticities of *TFP* with respect to *GER* and *IER*			
GER	0.26**	0.20***	0.20***
IER	0.28**	0.23**	0.22**
Diagnostics			
R-squared	0.6216	0.5112	0.5099
Adjusted R-squared	0.31	0.3687	0.3923
F-statistic	1.9950	3.5865	4.3356
Prob. (F-statistic)	0.0885	0.0087	0.0039
Number of observations	32	32	32

Note: *p* values are reported in parentheses. Standard errors are corrected for heteroskedaticity. Statistical significance at the 1, 5 and 10% levels is indicated by ***, *** and *, respectively.
Source: Authorǿs calculations.

Table 3 Tests on residuals: Model 3

Residual Unit root test :			
Null Hypothesis: residuals have a unit root			
Exogenous: Constant			
Lag Length: Automatic			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-6.712	0.0000
	1% level	-3.662	
Test critical	5% level	-2.960	
values:	10% level	-2.619	
Serial correlation test:			
Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.82315	Prob. F(1,24)	0.1895
		Prob. Chi-Square(1)	0.1328

Note: *MacKinnon (1996) one-sided p-values.
Source: Authorôs calculations.

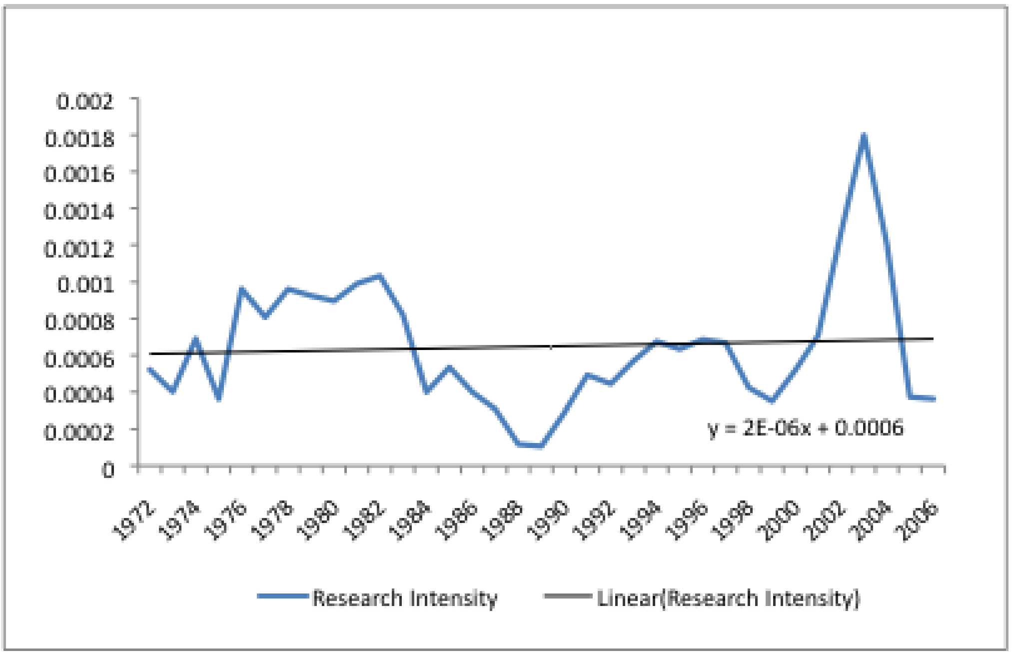
Table 4 Contributions to growth of real output, 1975 to 2006

(units: millions of Rupiah, 1975 prices)

Projected contribution to growth,1975 to 2006:	Increase in level	Per cent of increase
Factor growth only	16,644	36.6
Changes in TFP due to:		
All factors except international and government research	-15,948	-35.1
International research	18,283	40.2
Government research	25,387	55.9
All explanatory factors	44,366	97.6
Actual increase	45,436	100

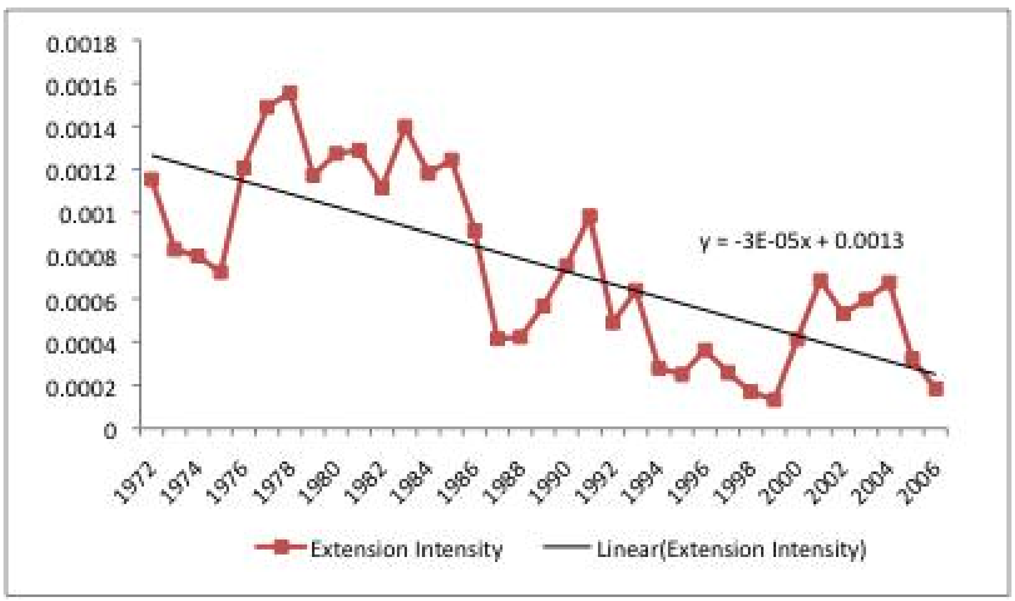
Source: Authorôs calculations.

Figure 1. Research intensity in Indonesian agriculture, 1972 to 2006



Note: Research Intensity is the ratio of government expenditure on agricultural research to total value-added in agriculture.
Source: Authorôs calculations using data provided by the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Bogor, and Central Bureau of Statistics, Jakarta.

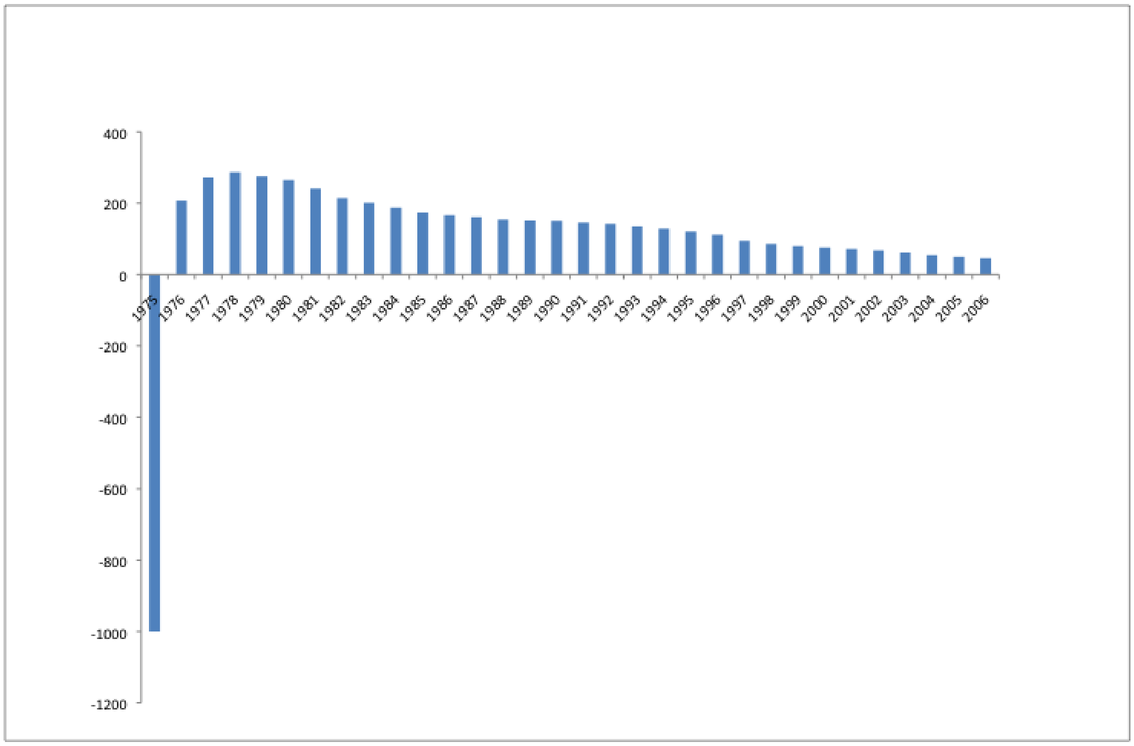
Figure 2. Extension intensity in Indonesian agriculture, 1972 to 2006



Note: Extension Intensity is the ratio of government expenditure on agricultural extension to total value-added in agriculture.
Source: Authorôs calculations using data provided by the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Bogor, and Central Bureau of Statistics, Jakarta.

Figure 3. Projected streams of net economic benefits arising from a 1 billion Rupiah increase in research expenditure in 1975

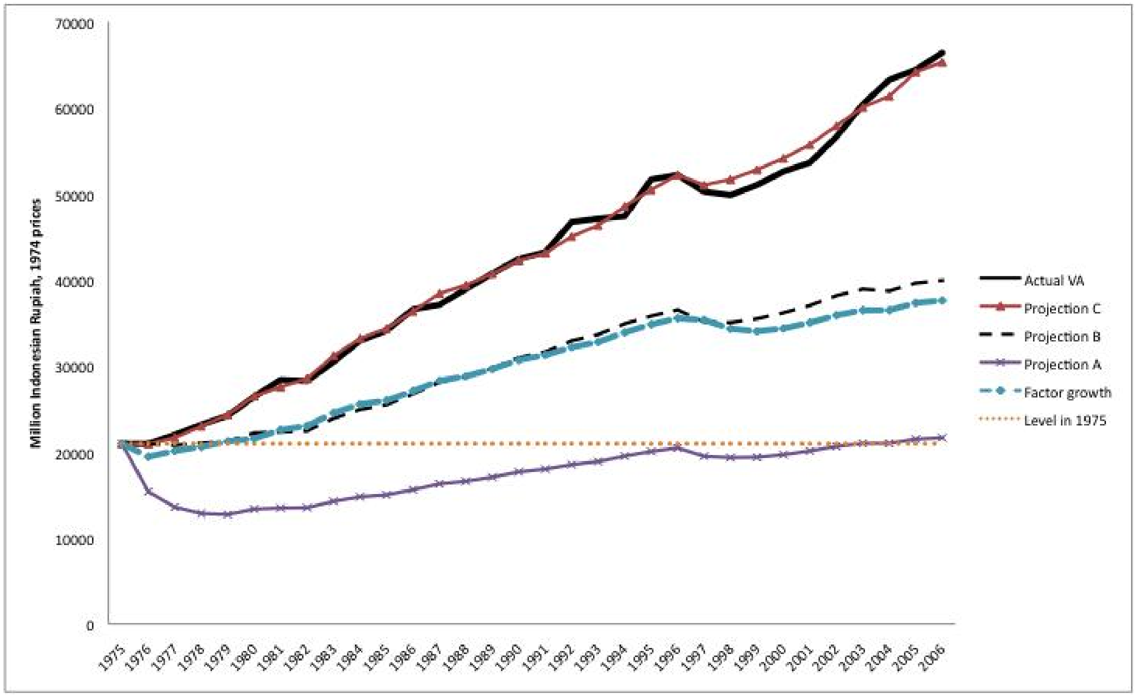
(units: millions of Indonesian Rupiah, constant 1974 prices



Source: authorĝs calculations as explained in the text.

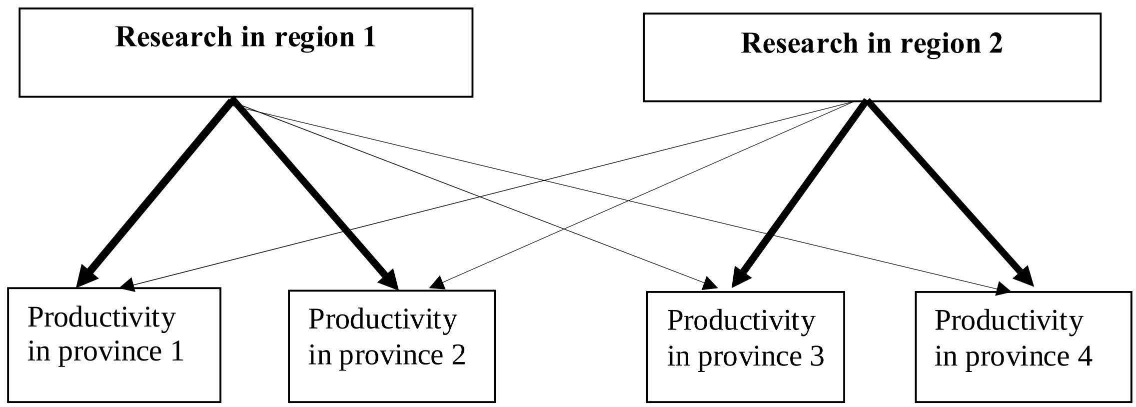
Figure 4. Projected streams of value-added in Indonesian agriculture

(units: millions of Indonesian Rupiah, constant 1974 prices)



Source: authorôs calculations as explained in the text.

Figure 5. No-spillover assumption of Rada, Buccola and Fuglie



Data Appendix A: Data used in regressions

Year	$\ln TFP$	D^1	D^2	$\ln GER$	$\ln IER$	*TRA*	*RF*	*FS*	$\ln GEE$
	A	B	C	D	E	F	G	H	I
1974	0.3365	0	0	8.6160	0.1439	-37.18	24.59	0.56	9.21
1975	0.3293	0	0	8.7990	0.2616	-32.32	25.97	0.56	9.41
1976	0.3221	0	0	9.2236	0.5912	-30.58	19.83	0.56	9.71
1977	0.3365	0	0	9.4806	0.8413	-29.51	21.76	0.54	10
1978	0.3646	0	0	9.7253	1.0717	-45.79	24.04	0.55	10.23
1979	0.3784	0	0	9.8907	1.2577	-43.58	23.67	0.55	10.35
1980	0.4511	1	0	10.0188	1.4080	-53.01	23.94	0.56	10.46
1981	0.4762	0	0	10.1501	1.5382	-46.09	25.86	0.59	10.57
1982	0.4511	0	0	10.2706	1.6582	-20.77	19.38	0.58	10.64
1983	0.4637	0	0	10.3443	1.7710	-35.41	22.87	0.58	10.74
1984	0.5008	0	0	10.3548	1.8716	-37.09	26.14	0.59	10.8
1985	0.5188	0	0	10.3876	1.9655	-35.47	22.27	0.58	10.87
1986	0.5481	0	0	10.4030	2.0531	-38.92	24.39	0.58	10.91
1987	0.5188	0	0	10.4024	2.1325	-50.14	21.44	0.57	10.9
1988	0.5481	0	0	10.3742	2.2032	-49.65	22.41	0.57	10.9
1989	0.5653	0	0	10.3458	2.2692	-53.87	24.00	0.57	10.91
1990	0.5710	0	0	10.3507	2.3306	-45.05	22.39	0.56	10.94
1991	0.5710	0	0	10.3964	2.3850	-43.71	23.63	0.55	11
1992	0.6206	0	0	10.4376	2.4433	-35.30	24.17	0.56	11
1993	0.6098	0	0	10.5063	2.4915	-31.04	16.39	0.54	11.03
1994	0.5822	0	0	10.5945	2.5360	-28.14	12.97	0.53	11.02
1995	0.6419	0	0	10.6710	2.5715	-26.83	16.03	0.54	11
1996	0.6313	0	0	10.7544	2.6027	-28.96	14.35	0.54	11.01
1997	0.5988	0	1	10.8297	2.6419	-16.96	11.16	0.52	11
1998	0.6206	0	1	10.8449	2.6765	-27.65	15.32	0.53	10.97
1999	0.6523	0	0	10.8549	2.7150	0.43	23.10	0.54	10.94
2000	0.6729	0	0	10.8823	2.7479	3.75	24.55	0.52	10.95
2001	0.6729	0	0	10.9364	2.7758	1.47	23.45	0.52	10.99
2002	0.7031	0	0	11.0672	2.8048	0.53	17.25	0.52	11.02
2003	0.7514	0	0	11.2476	2.8307	6.62	15.49	0.52	11.06
2004	0.7975	0	0	11.3334	2.8457	-5.30	12.75	0.50	11.1
2005	0.7930	0	0	11.3232	2.8623	-2.48	16.61	0.50	11.09
2006	0.8154	0	0	11.3140	2.8771	-3.77	14.91	0.49	11.07

Data sources: Column A from Fuglie, (2010).Columns Dand Ifrom Indonesian Center for Agricultural Socio-economic Policy Studies, Bogor, Indonesia.(ICASEPS). Column D from Suphannachart and Warr (2011)).Column G from online data set accompanying Dell, Jones and Olken(2008).Column H from Central Bureau of Statistics, Jakarta.

Data Appendix B: Data used in calculating IRR for research

Year	Value-added	TFP	Factor Index
	A	B	C
1975	20960.00	1.39	15079.14
1976	20960.00	1.38	15188.41
1977	22001.49	1.4	15715.35
1978	23173.17	1.44	16092.48
1979	24214.66	1.46	16585.38
1980	26427.83	1.57	16833.01
1981	28380.62	1.61	17627.71
1982	28250.43	1.57	17993.91
1983	30463.60	1.59	19159.50
1984	32937.14	1.65	19961.90
1985	34108.82	1.68	20302.87
1986	36582.36	1.73	21145.87
1987	37103.11	1.68	22085.18
1988	38925.71	1.73	22500.41
1989	40748.32	1.76	23152.46
1990	42440.75	1.77	23977.82
1991	43221.86	1.77	24419.13
1992	46736.89	1.86	25127.36
1993	47127.45	1.84	25612.75
1994	47387.83	1.79	26473.65
1995	51683.98	1.9	27202.09
1996	52204.72	1.88	27768.47
1997	50251.93	1.82	27610.95
1998	49861.37	1.86	26807.19
1999	51033.04	1.92	26579.71
2000	52595.28	1.96	26834.33
2001	53636.77	1.96	27365.70
2002	56631.06	2.02	28035.18
2003	60406.46	2.12	28493.61
2004	63270.56	2.22	28500.25
2005	64442.24	2.21	29159.38
2006	66395.03	2.26	29378.33

Data sources: Column A from the output index reported in Fuglie (2010), converted to value form at constant prices with data for 1975 from Central Bureau of Statistics, Jakarta. Column B from Fuglie (2010), re-indexed to 1961= 1. Column C calculated as C = A/B.