Arndt-Corden Department of Economics
Crawford School of Public Policy
ANU College of Asia and the Pacific

Research and productivity in Indonesian agriculture

Peter Warr

Australian National University,
Canberra

February 2022

Working Papers in Trade and Development

No. 2022/02

This Working Paper series provides a vehicle for preliminary circulation of research results in the fields of economic development and international trade. The series is intended to stimulate discussion and critical comment. Staff and visitors in any part of the Australian National University are encouraged to contribute. To facilitate prompt distribution, papers are screened, but not formally refereed.

Copies are available at https://acde.crawford.anu.edu.au/acde-research/working-papers-trade-and-development

Research and productivity in Indonesian agriculture*

Peter Warr

Australian National University,
Canberra

Total factor productivity growth contributed 38 per cent of Indonesia's agricultural output growth from the mid-1970s to the mid-2000s. This study uses time series data analysed with the error correction mechanism to examine the contribution of Indonesian publicly funded agricultural research to this outcome, allowing for other possible determinants of productivity growth, including international agricultural research, extension, government price policy and weather. The results imply a 27% real annual rate of return from a marginal increase in Indonesian agricultural research expenditure. Indonesia's public agricultural research explains virtually all of its agricultural total factor productivity growth between 1975 and 2006.

Key words: Agricultural research; Indonesia; error correction mechanism.

JEL codes: O13; O33; C22.

* The author gratefully acknowledges the outstanding research assistance of Hemantha Ekanayake, helpful discussions with Anne Booth, David Dawe, Waleerat Suphannachart and Peter Timmer, and kind assistance with data from the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Ministry of Agriculture, Government of Indonesia, Bogor. The author is responsible for all defects.

1. Introduction

Globally, publicly funded in-country agricultural research has been a major contributor to productivity growth within agriculture with high estimated economic rates of return (Ruttan 2002, Alston and Pardey 2014, Mellor 2017).[1] In summarizing the vast literature on this subject, Mellor writes (p. 151):

> The foundation for agriculture's role in the economic transformation is largely public modern science institutions producing a steady flow of improved technology. That technology must be locally based to ensure suitability to highly variable local conditions.

A recent review (CoSAI 2021) estimates that of roughly US$ 60 billion of global annual investment in agricultural innovation, 60 per cent derives from developing country governments (dominated by China), with 25 per cent from the global private sector (mainly large corporations) and about 10 per cent from aid and development partner governments. But the experience of individual developing countries in promoting agricultural productivity growth through publicly funded research has varied widely (Evenson and Gollin 2007, Fuglie *et al.* 2020).

Indonesia is a net importer of almost all of its principal food commodities, provoking constant anxiety about food security and agricultural productivity (Timmer 2015). The Covid-19 pandemic has added to those concerns (Patunru and Amanta 2021). Detailed estimates of total factor productivity (TFP) in Indonesian agriculture from Fuglie (2010), summarized in Figure 1, imply that over the three decades ending in 2006 average growth of agricultural TFP (TFPG) was 1.4 per cent per annum. Agricultural TFPG thus accounts for 38% of agricultural real value-added growth and 6.1 per cent of total real GDP growth.[2] This proportional contribution of TFP to the growth of agricultural output, though substantial, is not especially

[1] Alston and Pardey (2014) point to a slowdown in global agricultural productivity growth, coinciding with a slowdown in global publicly funded research.

[2] The annual growth rate of agricultural value-added was 3.68%, accounting for 16% of real GDP growth over the same period. Calculated using the regression-based semi-logarithmic linear trend method from data on agricultural VA and GDP from Central Bureau of Statistics, Jakarta.

high by Asian standards (Ruttan 2002, Avila and Evenson 2010, Fuglie *et al.* 2020). Moreover, the annual rate of agricultural TFP growth has slowed.[3] Refocusing attention on the determinants of productivity in Indonesian agriculture is thus of great policy interest.[4]

The analysis below provides a national level time series statistical analysis, covering the years 1975 to 2006, of the relationship between real in-country government expenditure on agricultural research and TFPG in Indonesian agriculture.[5] The national data internalize any possible inter-regional 'spill-overs' between research in one region and productivity in others, shown by past research on Indonesia and elsewhere to be a potentially important issue. The statistical analysis controls for other possible determinants of productivity, including 'spill-ins' from international agricultural research, infrastructure investments, extension, government protection policy, changes in the composition of agricultural output, weather changes and epidemics. The econometric methodology uses the error correction mechanism (ECM) of Hendry (1995), designed for the analysis of time series data and characterized by the separation of long-run causal relationships of interest from short-run dynamics and allowing for flexible lags in the relationship between research and productivity.

The results show that over the three decades covered by the data, expenditure on public agricultural research had a significant effect on total factor productivity in Indonesian agricultural production, with an estimated long-run impact elasticity (per cent change in total factor productivity from a 1 per cent increase in research expenditure) of 0.2. Based on the

---

[3] This point is confirmed by regressing the logarithm of Fuglie's TFP index, cited above, on time and time-squared. The estimated coefficients on these variables are positive and negative, respectively. Both are significant at the 95% confidence level.

[4] The issues involved in assessing the productivity impact of research are of more than academic concern in Indonesia. In April 2021 a new 'science super-agency', to be called BRIN, was announced. It is to oversee virtually all publicly funded scientific research, reporting directly to the President, with funding to be dependent on demonstrated performance. Evaluation of research impact is currently a hotly debated policy issue within Indonesia.
[*Source*: https://www.nature.com/articles/d41586-021-02419-4]

[5] Privately funded agricultural research is relatively minor in Indonesia, varying between 3 and 7 percent of the level of public agricultural research expenditure. Most has been in estate crops such as rubber and palm oil (Pray and Fuglie 2001).

econometric results summarized above, a projection is made of the counterfactual impact on the time path of total factor productivity resulting from a hypothetical 1 billion Indonesian Rupiah increase in agricultural research, occurring in the year 1975, controlling for the factors listed above. The impact on the time path of agricultural value-added is estimated from this analysis, implying an annual real rate of return of 27%. Finally, it is estimated that virtually all of Indonesia's agricultural productivity growth between 1975 and 2006 can be attributed to public agricultural research.

2. Analytical framework

The primary concept is a production function for agricultural value-added that distinguishes between, first, conventional farm-level inputs – labor, land and capital – and second, possible contributors to farm output that operate beyond the farm level. The latter include research, extension, investments in public infrastructure like irrigation, government tax and trade policy, changes in the share of food crops in the value of agricultural output, weather and disease outbreaks. Studies of TFP in agriculture have often taken explicit account only of farm-level inputs, as measured in farm-level surveys, assigning the combined contribution of beyond-farm inputs to an unexplained residual, using the conceptual framework underlying the seminal TFP studies of Solow (1957), Jorgenson and Griliches (1967) and Jorgenson (1995).

Let the production function for agriculture at time *t* be $Q_t = h(X_t, Z_t)$, where Q_t denotes real value-added in year *t* from agriculture, broadly defined (the value of total output of crops, livestock and aquaculture minus the value of all intermediate inputs such as fertilizer, fuel and chemical inputs used in these industries, each measured at constant prices), X_t denotes current inputs, in real terms, of the conventional on-farm factors of production – land, labor and capital – and Z_t represents the non-conventional, off-farm factors mentioned above. The latter affect the productivity of the on-farm inputs. In the case of man-made capital inputs, Z_t represents the current real stock of these assets, the results of past investments.

By definition, TFP is an index of aggregate output (value-added) relative to an index of aggregate conventional farm level factor inputs. It is therefore a function of the levels of non-conventional inputs. It is convenient for exposition, but not analytically necessary, to assume that the function h is multiplicatively separable between conventional and non-conventional inputs, giving $h(X_t, Z_t) = f(X_t)g(Z_t)$. Writing P_t for TFP at time t

$$P_t = Q_t/f(X_t) = g(Z_t). \tag{1}$$

Assuming $h(X_t, Z_t)$ to be differentiable, it is familiar that TFP growth is given by

$$p_t = q_t - \sum_{i=1}^{I} \varepsilon_t^i \, x_t^i = \sum_{j=1}^{J} \eta_t^j \, z_t^j, \tag{2}$$

where p_t, q_t, x_t^i and z_t^j denote the proportional rates of change of P_t, Q_t, X_t^i and Z_t^j, respectively.[6] The parameters $\varepsilon_t^i = h_{X_i} X_t^i / Q_t$ and $\eta_t^j = h_{Z_j} Z_t^j / Q_t$, not necessarily constant over time, denote the elasticities of output with respect to the inputs X_t^i and Z_t^j, respectively, where h_{X_i} and h_{Z_j} denote the partial derivatives of $h(X_t, Z_t)$ with respect to X_t^i and Z_t^j, respectively. Equivalently, TFPG is measured as the residual part of the growth in output (value-added) that is left unexplained by the growth of conventional factor inputs. The focus of this study is on the function $g(Z_t)$.

[6]Equation (1) rests on the simplifying assumption of multiplicative separability, but (2) does not require it.

3. Past studies on agricultural research in Indonesia

Surveys of the international literature on productivity growth in agriculture confirm that domestic agricultural research normally contributes significantly to it, though the magnitudes vary (Ruttan 2002, Evenson and Gollin 2007, Avila and Evenson 2010, Alston and Pardey 2014). In the case of Indonesia, Salmon (1991) estimates high rates of return to research on rice production, confirmed for a range of food crops by Rosegrant, Kasryno and Perez (1998). A more comprehensive study of Indonesia's agricultural research by Evenson, Abdurachman, Hutararat and Tubagus (1994, 1997) – subsequently EAHT – describes in detail the organization of agricultural research within the country and analyzes its impacts on agricultural TFP.

EAHT describe Indonesia's agricultural research as organized primarily, though not exclusively, on a commodity basis, with nation-wide mandates[7] (pp. 552-4).[8] One major institution specializes in research on irrigated rice (Sukamandi Research Institute in Central Java),[9] another specializes on upland rice and pioneering food crops (Bogor Research Institute for Food Crops in West Java), another focuses on other upland food crops, including peanuts (Sukarami Research Institute in South Sumatra), another on field crop research in swampy areas (Banjarbaru Research Institute in Kalimantan), one on vegetables (Lembang Research Institute in West Java), one on fruit (Solok Research Institute in West Sumatra), and so forth, as well as other institutes specializing in aquaculture and livestock.[10]

---

[7] See also Fuglie and Piggott (2006), along with Rada and Fuglie (2012) for discussion of these institutional issues.

[8] Cited page numbers of EAHT refer to the 1997 version because of its online availability. The 1994 Yale working paper version cited by Rada *et al*. (2011) – see below – is identical to it.

[9] Ruttan (1982, pp. 165-6, 179) describes the decision in the mid-1970s to relocate the national rice research program from Bogor to Sukamandi in central Java. He criticizes the relocation mainly because the isolation of the new site made it more difficult to recruit highly qualified research staff. He attributes the decision to misguided pressure from the funding source, the World Bank. Barker, Herdt and Rose (1985, pp. 265-266) argue that this new location, within the irrigated rice region of Java, led to excessive focus on research on irrigated rice, relative to rainfed rice.

[10] Some smaller institutes have had less tightly specialized research mandates. A long-term historical study by van der Eng (1996, p. 76) supports the overall picture of commodity-focused, rather than region-focused organization of Indonesian agricultural research, described by EAHT: "In 1980 a clear organizational structure

In analyzing the impacts of research investments, EAHT use commodity-specific data at a regional level for each of six regions of Indonesia. Statistically significant nation-wide impacts of research on productivity were reported for almost all of the 22 commodities analyzed, including the major food crops (irrigated rice, rainfed rice, maize and soybeans) and most vegetables (p. 575). The analysis estimates rates of return to research expenditures that are high by international standards. The study attributes this to the low level of research expenditure relative to the value of agricultural output in Indonesia, compared with neighboring countries like Thailand and Malaysia, combined with diminishing marginal returns to investment in agricultural research. Another possible explanation is that the EAHT analysis, in common with most such studies, does not control for the 'spill-in' effects of international agricultural research, potentially overly attributing productivity gains to domestic research.

The EAHT methodology emphasizes 'technological diffusion' across regions – the impact that commodity-specific research and development expenditures occurring in each of the six regions may have on productivity in that commodity within other regions of the country (p. 563). The findings conclude that these cross-regional research 'spillovers' were important for most individual commodities, including all food crops except mungbeans (p. 566). The cross-regional pattern of these estimated spillovers varied across commodities, generally reflecting the regional distribution of production of the commodity concerned. For example, significant inter-regional diffusion was found for irrigated rice and maize within

---

was put in place. It had central research stations for food crops, horticulture, smallholder cash crops, fisheries and animal husbandry, each of which headed a group of branch stations." Over time, the centralized research stations remained dominant but the less specialized branch stations reflected "the beginning of a trend towards greater regional diversification in research to suit local circumstances."

Java, but not elsewhere, whereas for soybeans and sweet potatoes significant diffusion was found between regions outside Java. EAHT therefore found that (i) the organization of Indonesia's agricultural research facilities presupposes significant research spillovers between regions, and (ii) these cross-regional spillovers are in fact significant.

A more recent paper by Rada, Buccola and Fuglie (2011) – subsequently RBF – reaches very different conclusions. The findings attribute most of Indonesia's agricultural TFP growth since the Green Revolution[11] to government tax and exchange rate policies and very little to government research:

> Among the range of interventions at government's disposal – trade restrictions, subsidies, price supports and taxes, and public research— the latter appears to have been least effective in boosting productivity growth. (p. 878).

The study uses data for 22 provinces in 5 regions of Indonesia, covering the years 1985 to 2005. The analysis divides total factor productivity growth over the period of their data (average annual growth rate 2.2%) into technical progress and technical efficiency components (average annual growth rates 2.4% and - 0.2%, respectively). Productivity growth consisted entirely of technical progress. The statistical analysis then relates technical progress in each province to agricultural research (measured as numbers of research employees) occurring within the region containing that province but not to research occurring in any other region. Possible inter-regional 'spill-overs' are thus ruled out. The 'spill-in' impact of international agricultural research is not controlled for.

[11] The Green Revolution (GR) is generally considered to have begun in the mid-1960s (Falcon 1970), but its end point is less clear. Evenson and Gollin (2002) argue that it continued at least to the end of the 1990s. Pingali (2017) places the end point at around 2005. According to these assessments, the data of both RBF (1985 to 2005) and the present study (1975 to 2006) are late-GR but not post-GR.

RBF conclude that the impact of domestic agricultural research was statistically significant but that it had "negligible influence on the production possibilities available to Indonesia's agricultural producers." (p. 875). The estimated research stock elasticities (percent change in output in three product categories resulting from a 1% rise in the stock of public research) were each "no more than 0.01%." But because the rate of technical progress was so much higher than that explained by public research, or the study's other control variables, the new technology must have derived from something else, not accounted for in the analysis. In recognition of this discrepancy, the study's conclusions speculate without evidence that this source must lie in vaguely described "informal and poorly sourceable influences for which measured government action does not account" (p. 878), also described as "informal technology diffusion" (p. 867).

In reaching these conclusions, RBF assume (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 (Evenson *et al.* 1994). Each province in our model is therefore assigned its region's research stock.

The assumption of no inter-regional spillovers from research is statistically convenient when regional data are being used, as in RBF. That strong assumption is undefended, except for the above reference to Evenson *et al.* (1994) – EAHT – implying that the latter source supports the assumption described. But as shown above, the findings of EAHT strongly indicate the importance of inter-regional spillovers in the Indonesian context, contradicting rather than supporting the RBF assumption. Clearly, if inter-regional spillovers are in fact significant, the

RBF estimates of research impact are biased downwards, perhaps substantially so, because only within-region impacts are captured by their analysis.

Many international studies confirm the importance of inter-regional spillovers (Alston 2002, Alston *et al.* 2011). Mellor (2017) argues that this issue is fundamental to assessing the impact of agricultural research:

> Most studies of returns to research show substantial spillover effects from the geographic area for which the research was financed. (p. 153).

Of course, Indonesia could be different and EAHT could be wrong.

In a subsequent extension of this analysis, using the same raw data set, Rada and Fuglie (2012) use provincial data on agricultural outputs and inputs to estimate provincial TFPG and then attempt to explain it. The explanatory variables include national level data on domestic agricultural R&D expenditure, separating (i) food crop and livestock research from (ii) plantation crops research, and also using (iii) aggregate data on the area planted to International Rice Research Intstitute (IRRI) rice varieties to proxy international technology transfers for food crops. These three national level variables are the same for all provinces. Inter-provincial research spillovers are not mentioned, but the analysis implicitly assumes them, contrary to RBF. Otherwise, using Indonesia's nation-level research data to explain provincial-level TFP would make no sense. An *ad hoc* trapezoidal lag structure with fixed weights over time is imposed to capture the time lags associated with research impacts.

The results confirm significant impacts of plantation crops research (variable (ii) above). When variables (i) and (iii) are included together, neither is statistically significant, with or without variable (ii). Each is significant only when the other is dropped. The findings thus fail to distinguish between the impacts of domestic and international research. When variable (iii) is omitted, the results on variable (i) imply an annual real rate of return to domestic food crop research of 19% and domestic plantation crop research of 39%. The earlier RBF findings are mentioned but the huge difference between them and those of Rada and Fuglie (2012) is not discussed. A obvious hypothesis is that whereas the Rada and Fuglie (2012) analysis implicitly captures domestic regional spillovers of research impacts, RBF excludes them.

3. Statistical methodology

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), allowing for different short-term and long-term relationships among variables, separating the long-run relationships of interest from short-run dynamics. The time series relationship between research and productivity involves important issues of research lags. A common practice has been to impose arbitrary restrictions on the lag structure such as the second-degree polynomial distributed lag (bell-shaped lag structure), or the rigid trapezoidal lag structures imposed by RBF and Rada and Fuglie (2012). Imposing a lag structure that is too short or is otherwise inappropriate can induce bias in the estimated research impact and associated rate of return (Alston, *et al.* 2000). The ECM does not impose an overly restrictive form of lags, allowing a "flexible description of a unimodal lag shape, with potentially different values for the mean and median lags" (Hendry 1995, p. 287).

The ECM also provides estimates with valid *t*-statistics even in the presence of endogenous explanatory variables (Inder 1993). A further advantage is that it does not require the variables under consideration to 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 (T^{G}), and Food crop share (S^{F}). All others are I(0). In these circumstances, the ECM approach minimizes the possibility of estimating spurious relationships, retaining the long-run information of interest without arbitrarily restricting the lag structure (Hendry 1995, pp. 286-294).

The long-run relationship of interest is given by

$$\ln P_t = \gamma^0 + \gamma^1 \ln R_t^G + \gamma^2 \ln R_t^I + \gamma^3 \ln E_t^G + \gamma^4 T_t^G + \gamma^5 H_t + \gamma^6 S_t^F + \epsilon_t \,. \quad (3)$$

We are interested in particular, in the parameters γ^1 and γ^2, indicating the long-run elasticities of P_t with respect to R_t^G and R_t^I, respectively. The ECM approach embeds this long-run relationship, lagged one period, within the equation to be estimated, using a sufficiently dynamic specification to capture short-run dynamics, including both lagged dependent and independent variables (Hendry 1995). Hendry shows that this approach minimizes the possibility of estimating a spurious regression.

The estimated equation is

$$\begin{aligned}\Delta \ln P_t = {} & \beta^0 + \beta^1 \ln P_{t-1} + \beta^2 \ln R_{t-1}^G + \beta^3 \Delta \ln R_t^G + \beta^4 \ln R_{t-1}^I + \beta^5 \Delta \ln R_t^I \\ & + \beta^6 \ln E_{t-1}^G + \beta^7 \Delta \ln E_t^G + \beta^8 T_{t-1}^G + \beta^9 \Delta T_t^G + \beta^{10} \ln H_{t-1} + \beta^{11} S_{t-1}^F \\ & + \beta^{12} D^1 + \beta^{13} D^2 + \beta^{14} \Delta \ln P_{t-1} + \varepsilon_t \qquad (4)\end{aligned}$$

The ECM, equation (4), forms the maintained hypothesis for specification search and can be estimated by OLS. Equation (4) is then ‘tested down’ by dropping statistically insignificant lag terms to obtain a parsimonious ECM. The final preferred model is required to satisfy standard diagnostic tests, including the Augmented Dickey-Fuller test for residual stationarity (ADF) and the Breusch-Godfrey LM test for serial correlation in the regression residual.[12]

[12] Suphannachart and Warr (2011, 2012) apply a similar approach to Thai agriculture.

4. Explanatory variables and data sources

The empirical analysis developed below is conducted at the Indonesian national level, using time series data covering the years 1974 to 2006, inclusive.[13] Since all variables are defined at the national level, no assumptions are made, or need to be made, about the existence or otherwise of cross-regional spillovers because any such effects are internalized within the national data. Within the function $g(Z_t)$, the vector Z_t is assumed to include the following variables (expected signs in parentheses):

R^G (+) = the stock of real Indonesian public agricultural research;

R^I (+) = the stock of real international agricultural research;[14]

E^G (+) = real government expenditure on agricultural extension;

T^G (+) = government trade and tax interventions;

H (+) = rainfall;[15]

S^F (+) = share of food crops in agricultural output; and

D (+/–) = dummy variables for idiosyncratic productivity-influencing events.

Total factor productivity (P): uses data reported and explained in Fuglie (2010), drawing upon earlier work by van der Eng (1996).[16] Fuglie describes 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.[17]

---

[13] The data begin in 1974 because this was the inception of Indonesia's modern agricultural research system (Rada and Fuglie 2012). The data end in 2006 because this is the final year of the detailed data set on agricultural productivity assembled in Fuglie (2010).

[14] Spillovers from international research are potentially important sources of productivity growth, but they have often been ignored in the literature on the impact of agricultural research, including Rada et al. (2011), resulting in a possible omitted variable bias (Alston 2002, Fuglie and Heisey 2007).

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

[16] Fuglie (2010) 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 1975 = 100 in the present study.

[17] Since the change in land quality through irrigation is incorporated into Fuglie's measurement of land inputs, it should presumably not be among the non-conventional inputs included in the vector *Z*. This assumption is tested and confirmed below.

Real stock of Indonesian government agricultural research (R^G): uses data on annual government expenditures on agricultural research provided by the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Ministry of Agriculture, Government of Indonesia, Bogor. The raw data are expressed in nominal local currency (Rupiah) at current prices, beginning in 1970. The data include government expenditures within Indonesia financed by foreign sources but not foreign expenditures occurring abroad. 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%.

Real stock of international agricultural research (R^I):[18] uses data on total research expenditure by the three major centers 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 R^G above.

Real stock of Indonesian government agricultural extension (E^G): data, deflator and conversion to stock form were as described under R^G above, using data provided by the Indonesian Center for Agricultural Socio-economic Policy Studies (ICASEPS), Ministry of Agriculture, Government of Indonesia, Bogor.

Government trade and tax interventions (T^G): measured as the Total Rate of Assistance to Indonesian agriculture, the Direct Rate of Assistance (DRA) to agriculture minus the DRA

[18] Spillovers from international research are potentially important sources of productivity growth, but they have often been ignored in the literature estimating the impact of domestic agricultural research, including Rada *et al.*, resulting in a possible omitted variable bias (Alston, 2002, Fuglie and Heisey, 2007).

to manufacturing, estimated and described in Fane and Warr (2009). These data were also used by Rada *et al.* as their measure of Indonesian agricultural price policy.

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

Share of food crops in total output (S^F): 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 food crops in total output declined while the share of estate crops – coffee, tea, palm oil and rubber – increased. Government research is more concentrated on food crops, so its effect on total agricultural productivity could have declined for this reason.

Dummy variables (D): the two dummy variables relate to: 1980, when agricultural output suddenly surged, due to unusually favorable climatic and pest control conditions; and 1997-98, when all sectors of the Indonesian economy were disrupted by the Asian Financial Crisis, including agriculture, though less so than most other sectors.

5. Regression results

The regression results are reported in Table 2.[19] Applying the Hendry general-to-specific approach, variables in Model 1 that were insignificant at the 90% confidence level were eliminated to obtain Model 2, and the same again, to obtain Model 3. All remaining variables are significant at the 95% confidence 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, as required, and the estimated model has no significant serial correlation.[20]

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

[20] 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.

The surviving long-run variables in Model 3 are government expenditure on research (R^G) international expenditure on research (R^I) and the two dummy variables reflecting important idiosyncratic events, all significant at the 99% confidence level. All other explanatory variables, including public agricultural extension expenditure[21] and government tax/protection policy[22], were insignificant at the 90% confidence level.[23] The long-run elasticities of *TFP* with respect to $R^G$and R^I (equation (3)) are given by $\gamma^1 = -\beta^2/\beta^1 =$ 0.20 and $\gamma^2 = -\beta^4/\beta^1$= 0.23, respectively, where β^1, β^2 and β^3 are the estimated coefficients on $\ln P_{t-1}$, $\ln R^G_{t-1}$ and $\ln R^I_{t-1}$ in equation (4), reported in Model 3 of Table 2. The negative and significant intercept term is important, implying that in the absence of the expansion of international research (*IER*) and government research (*GER*), total factor productivity would have declined.

The parameter $\gamma^1 = 0.20$ is the estimated elasticity of TFP with respect to the stock of public agricultural research. The definition of TFP implies that $q_t = p_t + f_t$, where the variables are the percentage changes in output, TFP and factor inputs, respectively. Holding factor inputs constant, $q_t = p_t$ and γ^1 is the long run percentage change in output from a 1% increase in the stock of public research.[24] It is at least 20 times the RBF estimate.[25] The large difference between these findings apparently derives from the latter's use of a time series of

---

[21] In 1975/76 public expenditure on research slightly exceeded that on extension. By 1990/91 expenditure on extension was more than three times that on research (van der Eng 1996, pp. 315-316). See also Booth (1988, pp. 130-131). The finding of the present study is that Indonesia's public agricultural extension activities are ineffective.

[22] As noted above, Rada *et al.* report significant productivity-raising effects of tax and protection policies. This finding seems implausible on *a priori* theoretical grounds because these policy instruments imply price-induced movements around the national production possibility frontier, not outward shifts in it.

[23] As discussed above, the expansion of irrigated area was allowed for in Fuglie's construction of the quality-adjusted land input variable and therefore should 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 when data on the infrastructure variable road length were introduced into Model 1.

[24] If an increase in the stock of public research does induce an increase in factor inputs, the elasticity of output with respect to the stock of public research is even larger.

[25] The estimate of 0.2 can be compared with the RBF estimate that the percentage change in output resulting from a 1% increase in the stock of public research was "no more than 0.01%" and the Rada and Fuglie (2012) estimates of the corresponding elasticities for food crops and plantation crops of 0.15 and 0.16, respectively.

regional data, with the imposed but unsupported assumption of no inter-regional spillovers from research, leading to downwardly biased estimates of research impact. International agricultural research also contributed with an estimated elasticity of TFP with the respect to the stock of research of 0.225.

6. The rate of return to domestic research

The marginal rate of return to Indonesia's domestic agricultural research is estimated through the following two projections. First, based on the estimated Model 3, a projection is made of the effect on the stream of TFP resulting from a hypothetical 1 billion Rupiah increase in the flow of domestic agricultural research investment in 1975, measured in 1974 prices, relative to its observed level in that year. All other right-hand side variables, including international research, are set at their observed levels. This hypothetical increase in the flow of investment is for one year only, reverting in all subsequent years to the observed level in the data. This is compared with the similar projection, again based on Model 3, in which this hypothetical increase does not occur. Along with all other right-hand-side variables, it remains at its level observed in the data in all years.

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. The two time series of the flows of agricultural research in each year, from 1975 onwards, are as follows:

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

Case 1: The flow, denoted f_t^1, 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 flow data in all following years. Thus $f_t^1 = f_t^0 + 1$ for t =1975 and $f_t^1 = f_t^0$ thereafter.

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 confirmed that the stock in year *t,* where *t* = 1975, 1976, …, 2006 is given by

$$s_t = s_{1974}/(1+d)^{t-1974} + \sum_{\tau=1975}^{t} f_\tau /(1+d)^{t-\tau} \quad (5)$$

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

$$s_t^1 - s_t^0 = 1/(1+d)^{t-1975}. \quad (6)$$

The difference in 1975 is 1, the amount of the hypothetical 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 $1/(1.05)^3$, 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 estimated Model 3 was used to project the levels of TFP implied by these two series of the stock of public agricultural research, combined with the observed levels in the data of all other right-hand-side variables. The model assumes that an increase in the stock of research in year *t* affects TFP starting in the following year. The projected levels of TFP resulting from the 1975 shock (Case 1) are thus calculated for each year beginning in 1976, and ending in 2006. The difference between the levels of TFP in each year under these two projections (Case 1 and Case 0) is the estimated impact of the 1 billion Rupiah spending increase occurring in 1975 on the level of TFP in each subsequent year.

Let P_t^0 denote the levels of TFP observed in the data and let $\hat{P}_t^0$ denote the projected series of TFP derived from the estimated Model 3 and the observed levels of all explanatory variables, including the observed level of public research (Case 0). The difference ($\hat{P}_t^0 -$

P_t^0) is model prediction error. Now let $\hat{P}_t^1$ denote the projected series of TFP when the real stock of public agricultural research takes the hypothetical path described above (Case 1), with all other explanatory variables again taking their observed values in the data. The two projected streams of TFP, $\hat{P}_t^0$ and $\hat{P}_t^1$, are the same in 1975 because an increase in the flow of government agricultural research in 1975 adds to the stock in 1975 but this affects TFP only in the following year.[26] The two series differ in all subsequent years. To obtain the projected TFP impact of the additional investment in research, we wish to compare $\hat{P}_t^1$ with $\hat{P}_t^0$. The estimated difference between these two streams of TFP is shown in Figure 2.[27]

To estimate the social value of these TFP impacts, we now estimate the levels of total agricultural value-added corresponding to these two series of TFP, $\hat{P}_t^0$ and $\hat{P}_t^1$, holding the levels of all factor inputs constant at their actual levels. The series $F_t^0 = V_t^0/P_t^0$ will denote the levels of actual factor input implied by the Fuglie data series on TFP, denoted P_t^0, indexed to 1 in 1961, and the official data on real value-added in agriculture, V_t^0. The series of value-added corresponding to the two projected series of TFP are thus $\hat{V}_t^0 = F_t^0\ \hat{P}_t^0$ and $\hat{V}_t^1 = F_t^0\ \hat{P}_t^1$, respectively. The difference between them is the projected social 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 $\hat{V}_t^1 - \hat{V}_t^0 = F_t^0(\hat{P}_t^1 - \hat{P}_t^0)$.[28]

---

[26] The dependent variable is $\Delta \ln P_t = \ln P_t - \ln P_{t-1}$ and the independent variables include $\ln R_{t-1}^G$ but not $\ln R_t^G$.
[27] We do not compare $\hat{P}_t^1$ with P_t^0 here, to avoid confounding the projected TFP impact of the increase in government research investment ($\hat{P}_t^1 - \hat{P}_t^0$) with model prediction error ($\hat{P}_t^0 - P_t^0$).

[28] The validity of this calculation does not require that factor inputs are unresponsive to increased TFP. Suppose the increase in TFP induces an endogenous change in total factor inputs in agriculture, from F_t^0 to F_t^1. The net social value of the increased agricultural value added is the difference between the total increase in agricultural value added and the social opportunity cost of the factor inputs needed to achieve it. The difference in agricultural value-added is now $F_t^1\ \hat{P}_t^1 - F_t^0\ \hat{P}_t^0 = F_t^0(\hat{P}_t^1 - \hat{P}_t^o) + \hat{P}_t^1(F_t^1 - F_t^0)$. But if factor inputs are priced at their social opportunity costs, the value of the second term is matched by an increase in the social cost of achieving the increased value-added. The net social benefit is measured by the first term. The point is that an increase in factor inputs gives rise to a corresponding opportunity cost elsewhere. An increase in TFP does not.

Figure 3 shows the estimated social value of the stream of net economic benefits arising from the 1975 investment, all expressed in billions of Rupiah in constant 1974 prices. In 1975 the net benefit is negative, representing the 1 billion Rupiah cost of the investment and the fact that benefits do not begin until the following year, at the earliest. In each subsequent year it is $\hat{V}_t^1 - \hat{V}_t^0$. The real internal rate of return (IRR) from this series of net benefits can be calculated as the real rate of discount that leads the series to have zero net present value in 1975. This is the value of *r* such that

$$\sum_{t=1976}^{2006} \left[(\hat{V}_t^1 - \hat{V}_t^0)/(1+r)^{t-1975} \right] - 1 = 0 \quad (7)$$

The real IRR calculated from equation (7), is 27 per cent, well above the required rate of return from public investment in Indonesia.[29]

7. The contribution of public research to TFP growth

The growth of TFP in Indonesian agriculture has been significant, but to what extent did Indonesia's public agricultural research contribute to this outcome? Figure 4 shows four data series of agricultural TFP from 1975 to 2006, described below, along with their growth rates, *g*,[30] building on the results presented above:

A. *Observed TFP*: the data on TFP estimated in Fuglie (2010); *g* = 1.41.
B. *Observed TFP in1975*: assumes no change in TFP from 1975 onwards; *g* = 0.
C. *Model-projected TFP including public research*: Projected TFP from Model 3 with all explanatory variables as in the data, including public agricultural research; *g* = 1.43.

[29] Asian Development Bank (2020) estimates that normal *ex post* annual rates of return from public infrastructure investments in Indonesia are between 10% and 18% and that the required *ex ante* rate is about 13%.
[30] These are linear trend growth rates, estimated from the regression $\ln P_t = a + gt$, where *t* is time.

D. *Model-projected value excluding public research*: Projected TFP from Model 3 with all explanatory variables as in the data except public agricultural research, which is held constant at its 1975 level; g = 0.13.

It is now readily seen that:

- The difference between A and B is the increase in TFP observed since 1975.
- The difference between C and A is model prediction error.
- The difference between C and D is the estimated contribution of public agricultural research to the increase in total TFP.
- The difference between D and B is the estimated contribution of all other factors to the increase in total TFP.

The results imply that in the absence of Indonesia's pubic agricultural research, TFP growth would have been roughly zero. Public research accounts for essentially all of the TFP growth observed over this period.

8. Conclusions

This paper studies the effects that publicly funded domestic agricultural research and international agricultural research each have on agricultural productivity within Indonesia. It uses time series data at the national level, internalizing inter-regional spillovers and thus imposing no assumption regarding them. The analysis utilizes a form of time series analysis – the Error Correction Mechanism (ECM) of Hendry (1995). The ECM improves upon the time series features of earlier analyses. It separates the long-run relationships from short-run dynamics, extracting the long-run information of interest without arbitrarily restricting the lag structure and minimizing the possibility of estimating spurious relationships when variables have different orders of integration.

The results indicate that between 1975 and 2006 both national-level public research within Indonesia and international agricultural research, conducted through the three major centers of the CGIAR system, contributed positively and significantly to agricultural productivity growth within Indonesia and thereby to the growth of agricultural output. Public research alone explains essentially all of the total factor productivity growth occurring between 1975 and 2006; without it, total factor productivity would barely have changed.

The findings imply a real annual rate of return from public agricultural research of 27%, holding other determinants of productivity growth constant. This exceeds the return normally expected from Indonesian public investments, reflecting under-investment in this form of public expenditure, but it is still lower than rates of return to agricultural research estimated in many international studies (Evenson 2001, Hazell 2010). The comparison is difficult. Among other factors, and unlike the present study, earlier estimates have seldom controlled for 'spill-ins' from agricultural research conducted internationally, potentially over-estimating the return to domestic research though mis-attribution.

A better-resourced research effort within Indonesia, in both quantity and quality, could undoubtedly have done better. Relative to the value of agricultural output, the level of research expenditure in Indonesia is low by Asian standards.[31] Nevertheless, the activity of adapting the products of international research to domestic conditions is evidently so productive that even an under-resourced research establishment can make a large contribution.[32] Unlike industrial production, the heterogeneity of agricultural production is such that much agricultural technology is location-specific (Ruttan 1992, Alston and Pardey 2014). Knowledge created elsewhere in the world is often not readily transferable to a developing country environment without the local adaptation that domestic agricultural research can provide.

[31] Pray and Fuglie (2001) estimate that Indonesia's public agricultural R&D intensity (spending on public agricultural R&D as a percentage of agricultural value-added) was 0.29% in 1985 and 0.24% in 1995. Comparable estimates for 1995 were: China 0.33%, India 0.37%, Malaysia 0.58%, Pakistan 0.16%, Thailand 0.69% and The Philippines 0.23%.

[32] The adaptive, rather than fundamental, nature of Indonesian agricultural research presumably explains the relatively short lags between research expenditure and estimated impact found in this study.

References

Alston, J. M. (2002) Spillovers. *Australian Journal of Agricultural and Resource Economics,* 46, 315-346.

Alston, J. M., Anderson, M. A., James, J. S. and Pardey, P. G. (2011). The Economic Returns to U.S. Public Agricultural Research. *American Journal of Agricultural Economics,* 93, 1257-1277.

Alston, J. M., Marra, M. C., Pardey, P. G. and Wyatt, T. J. (2000) Research Return Redux: A Meta-Analysis of the Returns to Agricultural R&D. *Australian Journal of Agricultural and Resource Economics*, 44, 185-215.

Alston, J. M. and Pardey, P. G. (2014). Agriculture in the Global Economy. *Journal of Economic Perspectives*, 28 (1), 121-146.

Asian Development Bank (2020). Public-Private Partnership Monitor: Indonesia, Asian Development Bank, Manila, December. Available at: https://www.adb.org/publications/public-private-partnership-monitor-indonesia

Avila, A. F. D. and Evenson, R. E. (2010). Total Factor Productivity Growth in Agriculture: The Role of Technological Capital. In Pingali, P. and Evenson, R. E. (eds) *Handbook of Agricultural Economics*, vol. 4, Amsterdam: Elsevier, 3769-3822.

Barker, R., Herdt, R. W. and Rose, B. (1985). *The Rice Economy of Asia*. Washington, DC, Resources for the Future and Manila, The International Rice Research Institute.

Booth, A. (1988). *Agricultural Development in Indonesia.* London and Sydney: Unwin Hyman.

Dell, M., Jones, B. F. and Olken, B. F. (2008). Climate Change and Economic Growth: Evidence from the Last Half Century. *NBER Working Pape*r #14131.

Evenson R. E. (2001) Economic Impacts of Agricultural Research and Extension. In Gardner, B. L. and Rausser, G. C. (eds.) *Handbook of Agricultural Economics,* vol. 1, Amsterdam: Elsevier, 573-628.

Evenson, R.E., Abdurachman, E., Hutabarat, B. and Tubagus, A. C. (1994). Economic Impacts of Agricultural Research in Indonesia. Economic Growth Centre, Yale University, New Haven, CT.

Evenson, R. E., Abdurachman, E., Hutararat, , B. and Tubagus, A. (1997). Contribution of Research on Food and Horticultural Crops in Indonesia: An Economic Analysis. *Ekonomi dan Keuangan Indonesia*, XLV, 551-578. [Available online at: https://www.lpem.org/repec/lpe/efijnl/199721.pdf]

Evenson, R.E. and Gollin, D. (2002). The Green Revolution: An End of Century Perspective. Department of Economics Working Papers 2002-07, Department of Economics, Williams College. Available at: https://web.williams.edu/Economics/wp/Gollin_The_Green_Revolution.pdf

Evenson R. E. and Gollin, D. (2007). Contributions of National Agricultural Research Systems to Crop Productivity. In Evenson, R. E. and Pingali, P. (eds) *Handbook of Agricultural Economics*, vol. 3, Amsterdam: Elsevier, 2419-2459.

Falcon, W. P. (1970). The Green Revolution: Generations of Problems. *American Journal of Agricultural Economics*, 52 (5), 698-710.

Fane, G. and Warr, P. (2009) Indonesia. In Anderson, K. and Martin, W. (eds), *Distortions to Agricultural Incentives in Asia,* Washington DC: World Bank, 165-196.

Fuglie, K. O. (2010). Sources of Growth in Indonesian Agriculture." *Journal of Productivity Analysis* 33, 225-240.

Fuglie, K., O. and Heisey, P. W. (2007). Economic Returns to Public Agricultural Research. *USDA Economic Brief No.10.* United States Department of

Agriculture, Economic Research Service. Available at http://www.ers.usda.gov/publications/eb10/eb10.pdf.

Fuglie, K. O. and Piggott (2006). Indonesia: Coping with Economic and Political Instability. In Pardey, P. G, Alston, J. M. and Piggott, R. R. (eds) *Agricultural R&D in the Developing World: Too Little Too Late?* International Food Policy Research Institute, Washington, DC, 65-104.

Fuglie, K., Gautam, M., Goyhal, A. and Maloney, W. (2020). *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*, Washington, DC: World Bank Group.

Hazell, P. B. R. (2010) An Assessment of the Impact of Agricultural Research in South Asia Since the Green Revolution. In Pingali, P. and Evenson, R. E. (eds) *Handbook of Agricultural Economics*, vol. 4 Amsterdam, North-Holland, 3469-3530.

Hendry, D. F. (1995) *Dynamic Econometrics,* Oxford: Oxford University Press.

Inder, B. (1993) Estimating Long-Run Relationships in Economics: A Comparison of Different Approaches. *Journal of Econometrics,* 57**,** 53-68.

Jorgenson, D.W. (1988) "Productivity and Postwar U.S. Economic Growth," *Journal of Economic Perspectives*, 2 (4), 23-42.

Jorgenson, D. W. (1995) *Productivity Volume 2: International Comparisons of Economic Growth,* London, The MIT Press.

Jorgenson, D. W. and Griliches, Z. (1967) The Explanation of Productivity Change. *The Review of Economic Studies,* 34**,** 249-283.

Makki, S. S., Thraen, C. S. and Tweeten, L. G. (1999) Returns to American Agricultural Research: Results from a Cointegration Model. *Journal of Policy Modeling,* 21**,** 185-211.

Patunru, A. and Amanta, F. (2021). COVID-19 Food Security and Trade: The case of Indonesia. In Lewis, B. D. and Witoelar, F. (eds) *Economic Dimensions of COVID-19 in Indonesia: Responding to the Crisis*. Singapore: Institute of Southeast Asian Studies, 114-136.

Pingali, P. L. (2012). Green Revolution: Impacts, Limits, and the Path Ahead. *Procedings of the National Academy of Sciences*, 109 (31), 12302-12308.

Pray, C. E. and Fuglie, K. (2001). Private Investment in Agricultural Research and International Technology Transfer in Asia. Economic Research Service, United States Department of Agriculture, Agricultural Economic Report No. 805.

Rada N. E., Buccola, S. T. and Fuglie, K. O. (2011). Government Policy and Agricultural Productivity in Indonesia, *American Journal of Agricultural Economics*, 93, 867–884.

Rada N. E. and Fuglie, K. O. (2012). Shifting Sources of Agricultural Growth in Indonesia. In Fuglie, K.P. , Wang, S. L. and Ball, V. E. (eds) Productivity Growth in Agriculture: An International Perspective, Oxford, UK: CAB International, 199-213.

Rosegrant, M. W., Kasryno, F. and Perez, N. D. (1998). Output Response to Prices and Public Investment in Agriculture: Indonesian Food Crops. J*ournal of Development Economics, 55*, 333-352.

Ruttan, V. W. (1982). *Agricultural Research Policy*. Minneapolis, University of Minnesota Press.

Ruttan, V. W. (2002). Productivity Growth in World Agriculture: Sources and Constraints. *Journal of Economic Perspectives,* 16**,** 161-184.

Salmon, D. C. (1991). Rice Productivity and the Returns to Rice Research in Indonesia. In Evenson, R. E. and Pray, C. (eds) Research and Productivity in Asian Agriculture. Ithaca: Cornell University Press, 133-154.

Solow, R. M. (1957) Technical Change and Aggregate Production Function. *Review of Economics and Statistics*, 39**,** 312-320.

Suphannachart, W. and Warr, P. (2011). Research and Productivity in Thai Agriculture. *Australian Journal of Agricultural and Resource Economics*, 55, 35-52.

Suphannachart, W. and Warr, P. (2012). Total Factor Productivity in Thai Agriculture: Measurement and Determinants. In Fuglie, K.P. , Wang, S. L. and Ball, V. E. (eds) Productivity Growth in Agriculture: An International Perspective, Oxford, UK: CAB International, 215-236.

Timmer, C. P. (2015). *Food Security and Scarcity: Why Ending Hunger Is So Hard*, Philadelphia: University of Pennsylvania Press.

van der Eng, P. (1996). *Agricultural Growth in Indonesia: Productivity Change and Policy Impact Since 1880*. Macmillan, New York.

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: Flow	-3.16	-4.291***	I(I)
Govt. expenditure in research: Stock	-3.484*		I(0)
Govt. expenditure in extension :Flow	-5.794***		I(0)
Govt. expenditure in extension :Stock	-11.44***		I(0)
Foreign research expenditure: Flow	-4.570***		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 99%, 95% and 90% confidence levels is indicated by ***, *** and *, respectively.
Source: Author's calculations.

Table 2: Estimation results

Dependent variable: $\Delta\ln P_t$ **Independent variables**:	**Model 1**	**Model 2**	**Model 3**
Constant	-1.4782	-1.1416***	-1.0555***
	(0.2616)	(0.0071)	(0.0007)
$\ln P_{t-1}$	-0.5791***	-0.5086***	-0.4994***
	(0.0034)	(0.0009)	(0.0004)
$\ln R^G_{t-1}$	0.1541**	0.1061***	0.0993***
	(0.0379)	(0.0038)	(0.0006)
$\Delta\ln R^G_t$	0.0154		
	(0.8643)		
$\ln R^I_{t-1}$	0.1646**	0.1176**	0.1122**
	(0.0304)	(0.0467)	(0.0365)
$\Delta\ln R^I_t$	1.3384*	1.0069**	0.9353***
	(0.0759)	(0.0223)	(0.0082)
$\ln E^G_{t-1}$	-0.0128		
	(0.9265)		
$\Delta\ln E^G_t$	0.2024		
	(0.4294)		
T^G_{t-1}	-0.0012*	-0.0001	
	(0.0973)	(0.7732)	
ΔT^G_t	-0.0004		
	(0.4705)		
$\ln H_{t-1}$	-0.0003		
	(0.8385)		
S^F_{t-1}	0.2688		
	(0.5651)		
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)
$\Delta\ln P_{t-1}$	0.0558		
	(0.7333)		
Long-run elasticities of P_t with respect to R^G_t and R^I_t			
R^G_t	0.266**	0.209***	0.200***
R^I_t	0.284**	0.231**	0.225**
Diagnostics			
R^2	0.6216	0.5112	0.5099
$\bar{R}^2$	0.3158	0.3687	0.3923
F-statistic	1.9950	3.5865	4.3356
Prob. (*F*-statistic)	0.0885	0.0087	0.0039
Number of observations (1975 to 2006)	32	32	32

Note: *p* values are reported in parentheses (.). Standard errors are corrected for heteroskedasticity.
Statistical significance at the 99%, 95% and 90% confidence levels is indicated by ***, *** and *, respectively.
Source: Author’s 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 values:	5% level	-2.960	
	10% level	-2.619	

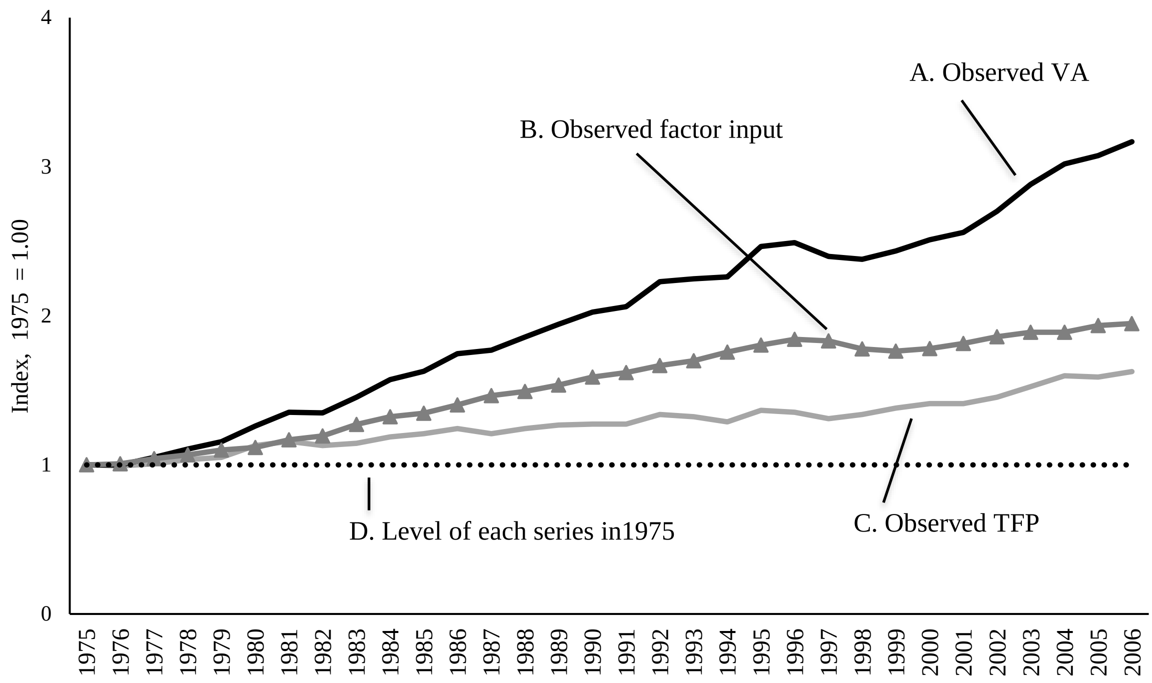
Serial correlation test:

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.82315	Prob. F(1,24)	0.1895
		Prob. Chi-Square (1)	0.1328

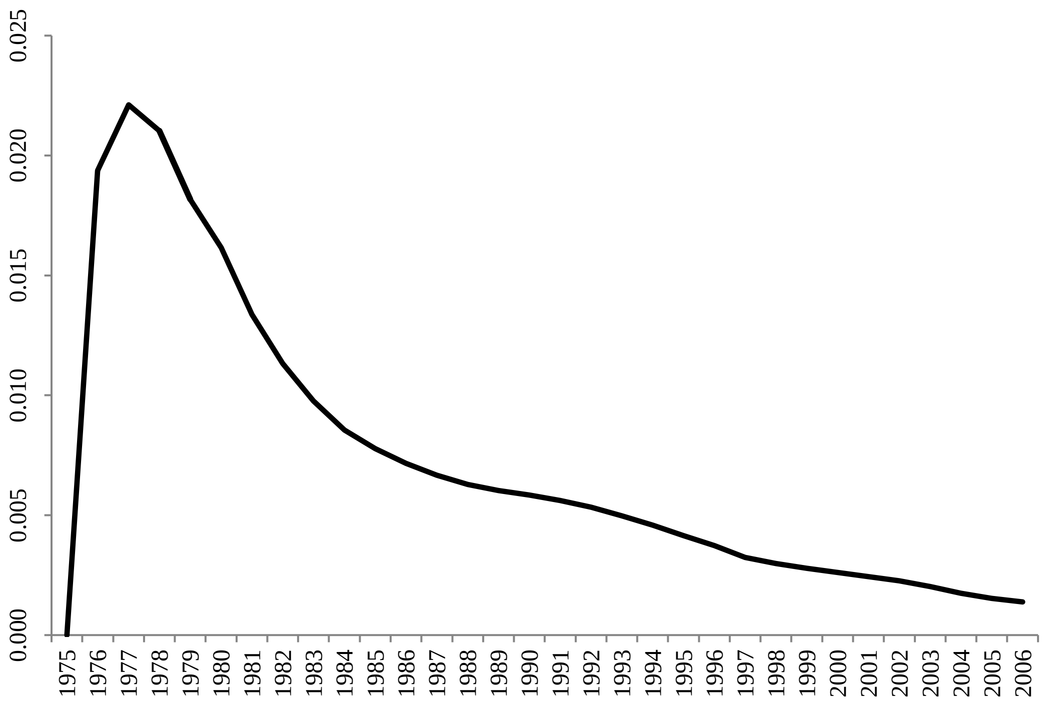
Source: Author's calculations.

Figure 1. Agricultural value-added, factor input and TFP, 1975 to 2006



Note: VA means value-added. TFP means agricultural total factor productivity.
Source: Data on VA from Central Bureau of Statistics, Jakarta. Data on TFP from Fuglie (2010). Data on factor input are the author's calculations from these series, using the identity Factor input = VA / TFP.

Figure 2. Marginal TFP effects from an increase in public agricultural research

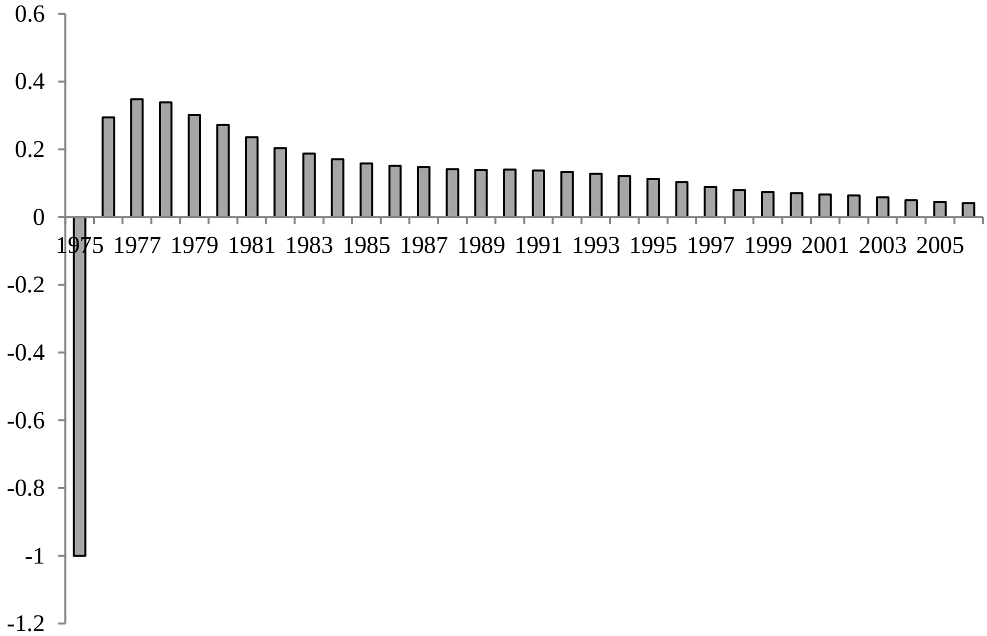


Note: TFP means total factor productivity. The diagram shows the estimated difference in Indonesian agricultural TFP between Case 1 (with a 1 billion Indonesian Rupiah marginal increase in public agricultural research in 1975) and Case 0 (with no such increase).

Source: Author's calculations

Figure 3. Stream of net economic benefits from an increase in public agricultural research

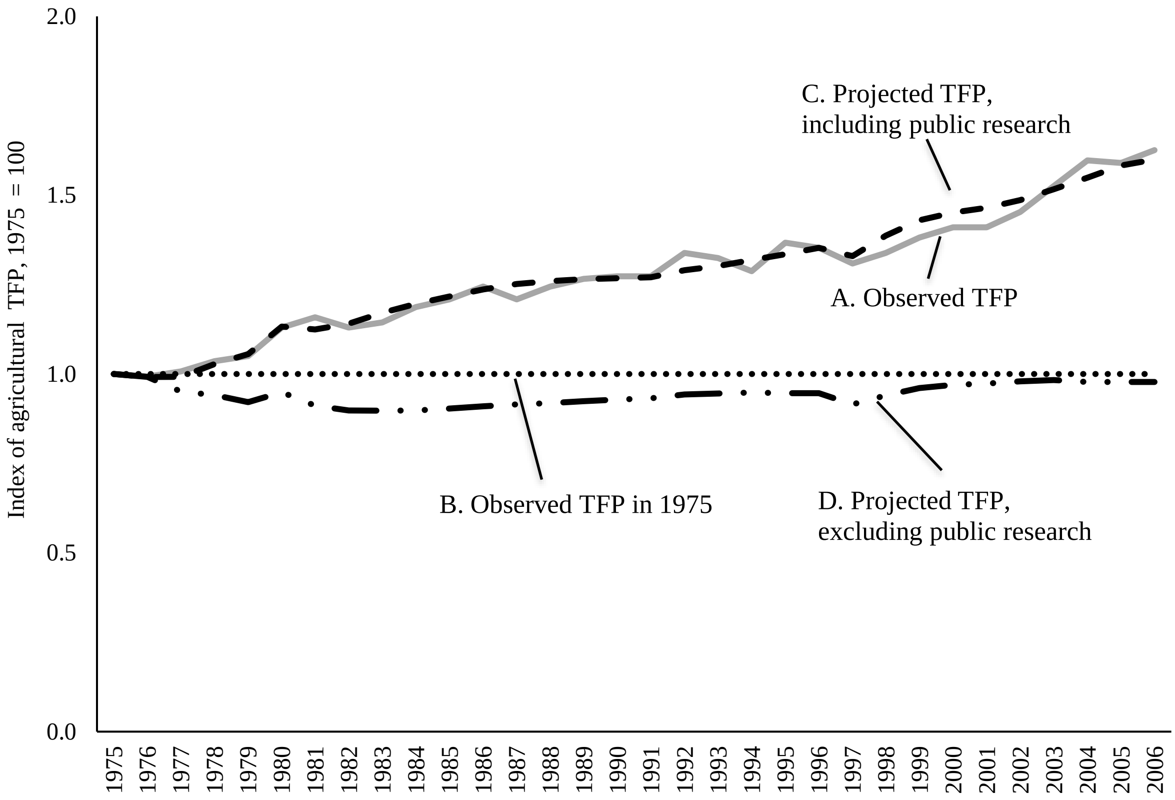
(Units: millions of Indonesian Rupiah, at constant 1974 prices)



Note: The diagram shows the estimated net economic benefits from a one-off 1 billion Rupiah increase in public agricultural research expenditure in 1975.

Source: Author's calculations as explained in the text.

Figure 4. Projected impact of public research on agricultural TFP



Source: Author's calculations, as explained in the text.

Supplementary Appendix A: Data used in regressions

Year	$\ln P$	$\ln R^G$	$\ln R^I$	$\ln E^G$	T^G	H	S^F	D^1	D^2
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
1974	0.3365	8.6160	0.1439	9.21	-37.18	24.59	0.56	0	0
1975	0.3293	8.7990	0.2616	9.41	-32.32	25.97	0.56	0	0
1976	0.3221	9.2236	0.5912	9.71	-30.58	19.83	0.56	0	0
1977	0.3365	9.4806	0.8413	10	-29.51	21.76	0.54	0	0
1978	0.3646	9.7253	1.0717	10.23	-45.79	24.04	0.55	0	0
1979	0.3784	9.8907	1.2577	10.35	-43.58	23.67	0.55	0	0
1980	0.4511	10.0188	1.4080	10.46	-53.01	23.94	0.56	1	0
1981	0.4762	10.1501	1.5382	10.57	-46.09	25.86	0.59	0	0
1982	0.4511	10.2706	1.6582	10.64	-20.77	19.38	0.58	0	0
1983	0.4637	10.3443	1.7710	10.74	-35.41	22.87	0.58	0	0
1984	0.5008	10.3548	1.8716	10.8	-37.09	26.14	0.59	0	0
1985	0.5188	10.3876	1.9655	10.87	-35.47	22.27	0.58	0	0
1986	0.5481	10.4030	2.0531	10.91	-38.92	24.39	0.58	0	0
1987	0.5188	10.4024	2.1325	10.9	-50.14	21.44	0.57	0	0
1988	0.5481	10.3742	2.2032	10.9	-49.65	22.41	0.57	0	0
1989	0.5653	10.3458	2.2692	10.91	-53.87	24.00	0.57	0	0
1990	0.5710	10.3507	2.3306	10.94	-45.05	22.39	0.56	0	0
1991	0.5710	10.3964	2.3850	11	-43.71	23.63	0.55	0	0
1992	0.6206	10.4376	2.4433	11	-35.30	24.17	0.56	0	0
1993	0.6098	10.5063	2.4915	11.03	-31.04	16.39	0.54	0	0
1994	0.5822	10.5945	2.5360	11.02	-28.14	12.97	0.53	0	0
1995	0.6419	10.6710	2.5715	11	-26.83	16.03	0.54	0	0
1996	0.6313	10.7544	2.6027	11.01	-28.96	14.35	0.54	0	0
1997	0.5988	10.8297	2.6419	11	-16.96	11.16	0.52	0	1
1998	0.6206	10.8449	2.6765	10.97	-27.65	15.32	0.53	0	1
1999	0.6523	10.8549	2.7150	10.94	0.43	23.10	0.54	0	0
2000	0.6729	10.8823	2.7479	10.95	3.75	24.55	0.52	0	0
2001	0.6729	10.9364	2.7758	10.99	1.47	23.45	0.52	0	0
2002	0.7031	11.0672	2.8048	11.02	0.53	17.25	0.52	0	0
2003	0.7514	11.2476	2.8307	11.06	6.62	15.49	0.52	0	0
2004	0.7975	11.3334	2.8457	11.1	-5.30	12.75	0.50	0	0
2005	0.7930	11.3232	2.8623	11.09	-2.48	16.61	0.50	0	0
2006	0.8154	11.3140	2.8771	11.07	-3.77	14.91	0.49	0	0

Note: Data definitions as provided in the text.

Data sources: Column [1] from Fuglie (2010). Columns [2] and [4] from data on the current price annual (flow) expenditures provided by Indonesian Center for Agricultural Socio-economic Policy Studies, Bogor, Indonesia. (ICASEPS), converted to constant price stock series by the author, as explained in the text, using wholesale price index data from Central Bureau of Statistics, Jakarta. Column [3] from Suphannachart and Warr (2011). Column [5] from Fane and Warr (2009). Column [6] from online data set accompanying Dell, Jones and Olken (2008). Column [7] from Central Bureau of Statistics, Jakarta. Columns [8] and [9] author's construction.