Uncovering Productivity Growth in the Disaggregate:

Indonesia's Dueling Agricultural Sub-Sectors

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Abstract

The success of seed-fertilizer technologies and government subsidies in attaining nearly self-sufficient rice production in the mid-1980s encouraged the Indonesian government soon afterward to shift resources away from food crops and toward export-oriented crops. These shifts were reinforced by trade liberalization and a sharp devaluation of the rupiah after the 1997 Asian financial crisis, which exerted Indonesia's comparative advantage in tropical perennial products. In the present paper, we ask whether such events have altered Indonesia's agricultural growth strategy from a food-crop to an export-crop one. With an innovative multi-output stochastic distance frontier model and provincial production and policy-related data from 1985 to 2005, we estimate technology growth by agricultural subsector and efficiency improvement by political jurisdiction. The perennial-crop sector is found to have achieved the highest technology growth rate, followed by the livestock and annual-crop sectors. We find overall productivity growth to have been moderate, and suggest that little of it can be attributed to Indonesia's public research efforts.

Keywords: agricultural research, Indonesia, Shephard distance function, stochastic frontier, technical change, technical efficiency

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Indonesia has historically focused its agricultural exports on cash crops. From 1975 to 1985, agricultural export values increased at an average annual rate of 10.61% (FAO 2009). The latter stages of this timeframe coincided with a shift in agricultural focus, as the Government's long-held food (rice) self-sufficiency policy goal gave way to an export-oriented development strategy. The economic transition was advanced after the Indonesian government adopted high-yielding rice varieties from the International Rice Research Institute (IRR) in the 1970s which, when complemented with fertilizer, allowed Indonesia by the mid-1980s to achieve nearly self-sufficient rice production.

However as the oil-boom waned by the early 1980s, the Indonesian government explored new strategies for supplementing oil and natural gas export revenues that had subsidized fertilizer consumption. Periodic currency devaluations (1978, 1983, and 1986) and economic deregulation catalyzed agricultural economy restructuring in an effort to improve farmers' terms of trade and assist them in competing with low world commodity prices (Timmer 2004). The impact of the Indonesian government's transition away from food-crop production is evidenced by Fuglie's (2009) index-number study of Indonesian aggregate farm productivity, which found an average annual total factor productivity growth rate of 2.18% between 1961 and 1984. Yet as resources shifted away from the agricultural sector, 1985 – 1997 productivity growth plummeted to 0.75%.

The Asian financial crisis of 1997 shocked the Indonesian economy, plunging its 1998 gross domestic product (GDP) growth rate to -13 percent (World Bank 2008) and its agricultural export value growth to -18.8% (FAO 2009). Regaining macroeconomic stability required instituting specific policy measures, negotiated with the International Monetary Fund (IMF), such as limiting food-crop tariffs to a maximum of five percent, deregulating the movement of inter-provincial agricultural commodities, and breaking the Government Logistical Agency's (Badan Urusan Logistik) monopoly over the trade rights for sugar, rice, wheat, soybeans, and garlic (ERS 2000; Timmer 2004). Indonesia was further required to sharply devalue the rupiah and liberalize trade, which exploited its tropical perennial crop comparative advantage and pushed Indonesia toward an export-led agricultural growth model. Agricultural export values faltered from 1999 to 2001, with an average annual growth of -4.9%, then dramatically increased from 2002 to 2007, surging by an annual average 23.3% and led predominately by growth in palm oil production (FAO 2009). Recent estimates show Indonesia to be the largest producer and second-largest exporter of palm oil, and fourth-largest coffee producer and exporter (USDA 2008).

As Indonesia now focuses on developing its food security strategy for the 2010 – 2014 planning period, the possibility arises of a return to a food-first production strategy. Any redirection of agricultural production requires the Indonesian government to utilize not just farm technology and prices, but the range of market opportunities at farmers' disposal. The effectiveness of any government policy requires an understanding of how government-provided technologies compete with non-public ones. As such, we ask how Indonesia's public investments (e.g., agricultural research, transportation infrastructure, and education) have affected relative technology growth in the perennial crop sub-sector – driving Indonesia's export-led growth – and in the annual crop sub-sector driving its food-first growth. Employing an innovative multi-output stochastic distance frontier, we identify the source of technical progress in the Indonesian agriculture's perennial, annual, and livestock sectors. We expand on Fuglie's (2009) aggregate agricultural total factor productivity study by using an original 1985 – 2005 provincial panel data set to distinguish technology growth by agricultural sub-sector, and technical efficiency by political boundary. Consistent with an export-led development strategy, we find that technology growth in perennial crops has risen faster than in annual crops and livestock. Yet we are unable to attribute such growth to government-sponsored research. Rather, private incentives introduced and reinforced by Indonesia's market transformation and trade liberalization appear to have been the primary productivity determinant.

Measuring Agricultural Progress

Our strategy is to characterize Indonesian farm technology by way of its output distance function (Färe and Primont 1995; Shephard 1953, 1970)

$$D_O(x_{kit}, y_{jit}, R_{it}, t) = \inf_{\theta}\{\theta > 0 : {y_{jit}}/{\theta} \in P(x^{o}_{kit}, R_{it}, t)\} \quad \forall x_{kit} \in \mathbb{R}^{N}_{+} \tag{1}$$

in which $y_{jit} \in \mathbb{R}^{M}_{+}$, $j = 1...M$ are scalar outputs; $x_{kit} \in \mathbb{R}^{N}_{+}$, $k = 1...N$ are scalar inputs; R_{it} are government research innovations; $t = 1...E$ are innovations introduced independently of government effort; $i = 1...I$ are the observations on technology, and $P(x^{o}_{kit}, R_{it}, t)$ is the producible output set. If outputs are weakly disposable, equation (1) implies $D_O(\cdot) \leq 1$ if and only if $y_{jit} \in P(x^{o}_{kit}, R_{it}, t)$. When $D_O(\cdot) = 1$, θ obtains its maximum at unity and outputs y_{jit} are located on the frontier of the producible output set, maximizing technical efficiency.

When producers instead operate strictly inside that frontier, that is $D_O(\cdot) < 1$, they are technically inefficient and in a way estimable with the frontier approach (Aigner, Lovell, and Schmidt 1977; Meeusen and Van den Broeck 1977). Because, along a ray from the origin, output distance (1) is a farm's deviation from its frontier, it can be regarded as a composite error term:

(2) $$D_O(x_{kit}\ ,\ y_{jit}\ ,\ R_{it}\ ,\ t;\ \beta\ ) \quad = \quad e^{v_{it} - u_{it}}$$

in which β is a parameter vector to be estimated; $u_{it} \sim N^{+}(0,\ \sigma^2_{u,it})$ is a nonnegative, half-normally distributed error representing an observation's distance from the frontier; and v_{it} an iid random noise with mean zero and variance σ^2_v (Aigner, Lovell, and Schmidt 1977). Error terms v_{it} and u_{it}, are assumed distributed independently of one another: $\sigma_{vu} = 0$. Specifying the left-hand-side of (2) in exponential form and substituting (2) into (1) expresses technical efficiency *(TE)* as

(3) $$TE_{it} \quad = \quad e^{h\ (\ln x_{kit}\ ,\ \ln y_{jit}\ ,\ \ln R_{it}\ ,\ t;\ \beta)} \quad = \quad e^{v_{it} - u_{it}}$$

where h is a function. To maintain the output distance function's linear homogeneity in outputs, that is $D_O(x_{kit}\ ,\ \omega y_{jit}\ ,\ R_{it}\ ,\ t\ ;\ \beta)\ =\ \omega\, D_O(x_{kit}\ ,\ y_{jit}\ ,\ R_{it}\ ,\ t\ ;\ \beta)$ for any $\omega > 0$ (Shephard 1970), we let $y^*_{jit}\ =\ y_{jit}\ /\ y_{mit}\ \neq\ +\infty$, where the m^{th} output is chosen as numeraire (Lovell, et al. 1994). Equation (3) then can be written

(4) $$-\ln y_{mit} \quad = \quad h(\ln x_{kit}\ ,\ \ln y^*_{jit}\ ,\ \ln R_{it}\ ,\ t\ ;\ \beta)\ +\ u_{it}\ -\ v_{it}.$$

Agricultural policy enters technology specification (4) in two ways. First, government research stocks *R*, along with non-government influences *t*, shift technology frontier *h*. Second, other government policies may shift farm technical efficiency. That is, farm production falls inside its frontier, and thus is inefficient, when farmers use obsolete technology, exercise poor management, or have other, unmeasured resource constraints, any of which may be policy-influenced (Hulten 2000). To estimate such influences, we ask how policy variables $\ln z_{cit}$, where $c = 1, \dots, C$ indexes policies, affect u_{it}'s second moment and hence expected technical efficiency. Following much of the literature, we use the exponential form $u_{it} = g(\mathrm{lnz}_{cit})\,\eta_{it}$ $= \exp\{f(\ln z_{cit};\, \mathbf{\Omega})\}\,\eta_{it}$ for this purpose, in which g and f are functions, $\mathbf{\Omega}$ is a parameter vector, and η_{it} is an iid random variable such that $\eta_{it} \geq 0$, $E(\eta_{it}) = 1$, and $V(\eta_{it}) = \sigma_{\eta}^{2}$ (Caudill, Ford, and Gropper 1995; Kumbhakar and Lovell 2000; Simar, Lovell, and Vanden Eeckaut 1994).

Note that one-sided inefficiency error u_{it} has constant coefficient of variation $\sigma_{\eta} \; = g(\cdot)\sigma_{\eta} \;/\; g(\cdot)E(\eta)$, so that its standard deviation and mean vary proportionately with one another. Hence also, in characterizing how policy variables $\ln z_{cit}$ affect the cross-province variation of this error and thus equation (4)'s heteroscedastic structure, function $g(\cdot)$ depicts how the policies affect national mean technical efficiency. In particular, taking the expectation of (3), expanding it in a Taylor series around $E(\eta) = 1$, and log differentiating with respect to $\ln z_c$ gives

$$\text{(5)} \qquad \frac{\partial \ln E(TE)}{\partial \ln z_c} \;=\; -\, e^{\,f(\ln \mathbf{z})}\, \frac{\partial f(\ln \mathbf{z})}{\partial \ln z_c} \;=\; -\, e^{\,f(\ln \mathbf{z})}\, \alpha_c$$

Knowledge of *u*'s heteroscedastic variance by way of $f(\ln \mathbf{z})$ and hence a_c are sufficient to assess policies' influences on mean efficiency. Finally, substituting u_{it}'s exponential form into (4) gives

$$\text{(6)} \qquad -\ln y_{mit} \;=\; h(\ln x_{kit},\ \ln y^{*}_{jit},\ \ln R_{it},\ t;\ \boldsymbol{\beta}) \;+\; \exp\{f(\ln z_{cit};\, \Omega)\}\,\eta_{it} \;+\; \varepsilon_{it}\ ,$$

where $\boldsymbol{\beta}$ is the technology vector and $\mathbf{\Omega}$ the inefficiency vector.

If government were effectively using its agricultural research establishment to support an export-led strategy, such as by devoting more of its varietal development efforts to export rather than food crops, one would expect technical change to expand producible output sets along the perennial crop dimension more than along the food crop dimension, an instance of technology bias toward perennials. Recent evaluations of Indonesian agricultural productivity have assumed unbiased technical change (Fuglie 2004, 2009). We instead test this assumption. Because $D_O \leq 1$ if and only if the technology transformation function is non-negative, bias can be defined in terms of the derivatives of D_O. In particular, where D_{O,Y_j} and D_{O,Y_i} are output distance derivatives with respect to Y_i and Y_j respectively, bias

$$(7) \qquad B_{ij} \equiv \partial \ln D_{O,Y_i} / \partial t - \partial \ln D_{O,Y_j} / \partial t = \partial \ln(\partial Y_j / \partial Y_i) / \partial t \qquad i \neq j,$$

is positive (negative) if technical change twists the production possibility frontier such that a smaller (greater) amount of Y_j is gained for a given reduction in Y_i. The i^{th} product's aggregate bias $B_i = \sum_{j \neq i}^{M} R_j B_{ij}$ then is its revenue-weighted average bias with respect to all other products (Antle and Capalbo 1988). Similar biases can be defined for inputs.

Assessing Indonesian Technology Change

Properly assessing Indonesian farm technology requires an understanding of its history. Indonesian agricultural research dates to the early 1800s, when the Dutch colonial government and plantation owners established research stations to support plantation crops and disease management. In the early 1900s, a Department of Agriculture was established to address food shortages generated by population growth (van der Eng 1996). But the Great Depression, World War II, the War of Independence (1945-1949), and nationalization of many foreign-owned plantations (1957) decimated research capacity. By the 1960s Indonesia had a negative agricultural trade balance and relied heavily on rice imports to feed its growing population. The "New Order" government of President Suharto elevated agriculture and food security to national priority later that decade and, in the 1970s, substantially boosted rice production by disseminating high-yielding rice varieties from the International Rice Research Institute (IRRI) and by using oil and gas revenues to subsidize fertilizers (Jatileksono 1987).

To strengthen its research capacity, the Indonesian government amalgamated the remains of its agricultural research institutes into the Agency for Agricultural Research and Development (AARD).[1] AARD staffing increased from 11 Ph.D. scientists at inception to 335 Ph.D.'s, 1,095 M.S.'s, and 2,187 B.S. scientists in 2003 (Fuglie and Piggott 2006). Despite this capacity growth, research suffered from low and unstable funding and occupies a substantially lower proportion of agricultural GDP than in other large Asian countries (Alston, Pardey, and Piggott 2006). Following the 1997-98 Asian financial crisis, operational allocations to the AARD fell by nearly one-half in constant PPP dollars (Fuglie and Piggott 2006). Under-funding has been especially severe in food and livestock research, which relies on central government development expenditures and donor aid. Plantation crop research, supported largely by state-owned and private plantations, has been generally better off (Fuglie and Piggott 2006). Expenditures per scientist at plantation crop institutes were in 1997-98 three times higher than at other AARD institutes (table 1).

Econometric Methods

We express the Indonesian farm output distance function $h(\ln x_{kit},\ \ln y^*_{jit},\ \ln R_{it},\ t;\ \boldsymbol{\beta})$ as

$$
\begin{aligned}
h(\ln x_{kit},\ \ln y^*_{jit},\ \ln R_{it},\ t;\ \boldsymbol{\beta}) &= \beta_0 + \sum_{k=1}^{N} \beta_k \ln x_{kit} + \sum_{j=1}^{M-1} \beta_j \ln y^*_{jit} + \beta \ln R_{it} + \beta_0 t \\
&+ \frac{1}{2}\sum_{k=1}^{N}\sum_{h=1}^{N} \beta_{kh} \ln x_{kit} \ln x_{hit} + \frac{1}{2}\sum_{j=1}^{M-1}\sum_{l=1}^{M-1} \beta_{jl} \ln y^*_{jit} \ln y^*_{lit} + \frac{1}{2}\beta_{00} t^2 \\
&+ \sum_{k=1}^{N}\sum_{j=1}^{M-1} \beta_{kj} \ln x_{kit} \ln y^*_{jit} + \sum_{k=1}^{N} \beta_{kt} t \ln x_{kit} + \sum_{j=1}^{M-1} \beta_{jt} t \ln y^*_{jit} + \beta t \ln R_{it},
\end{aligned} \tag{8}
$$

where R_{it} is public agricultural research stock and perennial-crop output is, owing to its wide statistical variation, used as numeraire; subscript j indexes perennial crops, annual crops, and livestock; i indexes 22 Indonesian provinces; and t is the time trend (1985-2005). Input set $x_{kit} \in \mathbb{R}^3$, $k = 1, 2, 3$ refers to labor, capital, and materials.

In stochastic frontier models, fixed-effects typically are specified through inefficiency error u_{it}. That unfortunately confounds province-wise and time-wise inefficiency with all other unobserved heterogeneity across provinces (Greene 2005). We thus follow a more intuitive approach of including a dummy variable P_i for each province, capturing cross-province, time-invariant, unobserved heterogeneity while permitting error u_{it} to capture any farm technical inefficiency.[2] Rewriting all non-research-stock variables, inclusive of provincial dummies, on the right side of (7), as $TL(P_i,\ \ln x_{kit},\ \ln y^*_{jit},\ t;\ \boldsymbol{\beta})$ and substituting into (5) gives

$$(9) \quad -\ln y_{mit} = TL(P_i\ ,\ \ln x_{kit}\ ,\ \ln y^*_{jit}\ ,\ t\ ;\ \boldsymbol{\beta}) + \beta \ln R_{it} + \beta t \ln R_{it} + exp\left\{ f\,(lnz_{cit}\ ;\boldsymbol{\Omega})\right\} + \varepsilon_{it}.$$

Two policy categories are examined for their productive efficiency impacts: physical capital investment, represented by road density; and human capital investment, represented by adult literacy rates. Road networks are the principal arteries for improved inputs and products – and part of the artery for information – linking producers with suppliers and customers. Furthermore, road density has been associated with economic growth in developing countries (Calderón and Servén 2004). Education provides the absorptive capacity for understanding and using new farm technologies, enhancing both technical and allocative efficiency.

For the sake of correcting any inefficiency error heteroscedasticity in (9), we characterize these policy influences in terms of their impacts on technical efficiency's cross-province variation rather than mean. As shown in connection with equation (5), implications then can be drawn for the mean. In particular, we regress

$$(10) \qquad \ln \sigma^2_{u,it} \;=\; \alpha_0 \;+\; \alpha_1 \ln RoadDensity_{it} \;+\; \alpha_2 \ln Literacy_{it} \;+\; \omega_{it}\;; \qquad \omega_{it} \sim N(0\,,\;\sigma^2).$$

simultaneously with (9) (Alvarez, et al. 2006; Battese and Coelli 1995; Caudill, Ford, and Gropper 1995; Wang 2002). This approach contrasts with the two-stage method in much of the agricultural productivity literature (Evenson and Fuglie 2009; Huffman and Evenson 2006; Yee, et al. 2002).[3]

Data

Agricultural production and policy data are drawn from multiple sources as described in Appendix table A1. Production is grouped into 5 regions and 22 provinces as summarized in Appendix table A2. On account of inadequate data quality, Papua, Maluku, and Nusa Tenggara Timur (NTT) are dropped from Eastern Indonesia, and DKI Jakarta from Java. Bali, traditionally part of Eastern Indonesia, is grouped with Java because of the similarity of their intensive rice-based agriculture.

The strength of this dataset lies in its rich time-series structure and annually recorded 50 outputs and 6 inputs. The 50 commodities for which data are available are aggregated into perennials, annuals, and livestock (table 2). Recorded inputs consist of agricultural land, labor, farm machinery (four sizes of tractors and threshers), animal draft power, fertilizers, and feed. These are aggregated into labor, capital, and materials as described below. Output and input prices are normalized to a 2002 basis using the World Bank’s Indonesian GDP price deflator (World Bank 2008).

Labor inputs consist of male and female agricultural laborers over the age of 15. Wages are simple averages across all operations (planting, plowing, and weeding) and provinces in a given region. Workers are assumed to receive the same wage, males working 300 days and females 250 days per year.

Capital inputs consist of cropland, farm machinery, and animal draft power. Machinery categories are large, medium, and small 4-wheel tractors, 2-wheel tractors, and power threshers, assuming an average horsepower of 40, 30, 25, 5, and 25, respectively. Machinery rental prices are, using FAO import price data for 4-wheel tractors, derived for a unit of annual horsepower, then prorated to a given machinery type based on its average horsepower. Draft animal power consists of the number of horses, cattle, and buffalo. Annual values of animal work services are obtained by amortizing the unit price of horses and buffalo over a 3-year period, again using FAO import price data, providing a service-flow input price for each animal type.

Land is quality-differentiated into six groups: irrigated wetland, rain-fed wetland (for rice), dryland, permanent cropland, temporary fallow, and meadow. Per-hectare land rental value is estimated as revenue net of the cost of the five inputs for which prices are available (feed, fertilizer, livestock, labor, and machinery) and divided by the quality-adjusted hectares of non-irrigated wetland equivalents. The following weights are used to quality-adjust the six land classifications: irrigated wetland (2), rainfed wetland (1), dryland and permanent cropland (0.75), and meadows and fallow (0.2). That is, irrigated rice land is assumed twice as productive as rainfed rice land, which in turn is more productive than other non-irrigated cropland or land in pastures and fallow.

Materials consist of animal feed and crop fertilizers. Feed quantities are estimated from time-constant, livestock-specific feed-to-meat conversion factors, multiplied by the relevant animal output quantity. In total feed expenditure estimates, feed price is assumed to be 1.5 times the real (2002 Rupiah basis) rice price. Rice and livestock feed prices differ from one another on account of feed processing costs. Nitrogen, phosphate, and potash fertilizer quantities are available at the national level and at the regional level in some years. Provincial-level estimates of fertilizer quantities applied to food crops are derived from average fertilizer application rates reported for these crops in province-level annual cost-of-production surveys. These application rates are then multiplied by harvested food-crop area. In the 1980s, food crops accounted for 80 percent of Indonesian fertilizer quantities (Central Statistics Bureau, 1990). Remaining fertilizer quantities are allocated to provinces based on the province's share of total cropland planted to plantation crops. Average farm-level fertilizer prices in Central Java are used to represent those in Java and Bali, and in North Sumatra to represent those in the rest of Indonesia.

To compute research stocks, weighted shares of agricultural scientist numbers, roughly reflecting salary differences (B.S., 0.3; M.S., 0.5; Ph.D., 1.0), were estimated for each region based on the location of the AARD research institute to which they were assigned. National AARD research expenditures were then multiplied by the share of total scientists per region to obtain estimates of region-specific research expenditures. Each province in our model is assigned its region's research stock.

Following Huffman and Evenson (1993), regional research stocks (R_{it}) follow a trapezoidal structure to reflect research's time-varying impacts. In particular, we assume a one-year lag before research expenditures $\left(AgExp_{bt}\right)$ begin to affect productivity, the effects then gradually increasing, peaking between the fifth and eighth year, diminishing, and finally terminating in year eleven through technology obsolescence:

$$\begin{aligned} R_{bt} &= 0.025 * AgExp_{b,t=-1} + 0.05 * AgExp_{b,t=-2} + 0.075 * AgExp_{b,t=-3} + 0.1 * AgExp_{b,t=-4} \\ &\quad + 0.125 * AgExp_{b,t=-5,-6,-7,-8} + 0.1 * AgExp_{b,t=-9} + 0.075 * AgExp_{b,t=-10,-11}, \end{aligned} \tag{11}$$

where regions and time are indexed by $b = 1...B$ and $t = 1...E$, respectively.

Road density is the sum of the length of asphalted road under a province's responsibility, divided by provincial area. Literacy is defined as the percentage of males and females over the age of 10 who use the Latin-based alphabet.

Results

Model (9) – (10) was estimated by STATA 10 with full information maximum-likelihood. Complete estimates of distance frontier (9) are provided in Appendix table A3, and of the policy impacts on technical inefficiency – equation (10) – in table 6. Estimated log likelihood value was 618.05. Fifteen of the 29 technology coefficients in (9) – excluding the provincial dummy estimates – are significant at 10 percent. Both literacy and road density significantly affect productive inefficiency.

Technical Progress

Equation (9)'s multi-output structure allows identifying the products most benefitting from technical progress. Applying the implicit function theorem to (9) and decomposing total technical change into its informal and formal sources, we have

$$(12) \qquad d\ln Y_{jit}\big/dt \quad = \quad \partial \ln Y_{jit}\big/\partial t \;+\; \left(\partial \ln Y_{jit}\big/\partial \ln R_{it}\right)\left(d \ln R_{it}\big/dt\right) .$$

Total technical change $d\ln Y_{jit} / dt$ is the sum of informal change $\partial \ln Y_{jit} / \partial t$ and formal change, itself the product of the output elasticity of agricultural research $\partial \ln Y_{jit} / \partial \ln R_{it}$ and of agricultural research's time rate of change $d \ln R_{it} / dt$. Informal change accounts for knowledge and embodied technology reaching farmers from sources outside the AARD agricultural research network. Formal change accounts for technology delivered from the AARD itself by way of the quality, and each region's share, of the stock of government research resources.

As table 4 shows, output elasticities with respect to government agricultural research stock, namely the percentage output shift explained by a percentage boost in government research, appear to have been negligible. At sample means, a one percent rise in AARD research has shifted the perennial-crop technical frontier outward by only 0.002% per year and the annual-crop frontier by only 0.001% per year. Given that government research stocks themselves have been rising 6.48% per year, the annual output boosts driven by government research have not exceeded 0.01%. In contrast, market and other non-government technology channels such as private agricultural research, international research centers, and word-of-mouth have accounted for an average per-annum output rise of 2.2% in the perennial crop sector, 1.7% in livestock, and 0.7% in the annual crops. Thus, nearly all of Indonesia's agricultural technology improvement during the industry-first, export-led 1985 – 2005 period appears to be explained by non-government channels. And the greatest improvement has by far been in the export perennial crops sector, where palm oil has had central position.

Perennial crops' superior technical performance during the past few decades has been consistent with Indonesia's industry- and export-oriented policy. One manner in which the superiority might have been achieved is through a research resource "bias," a policy preference for funneling innovation more into the perennial-crop than into the livestock or annual-crop sectors. That would have tilted the production possibility sets in the direction of perennial crops, leading to the high perennial output growth – at given factor levels and price ratios – that we observe. Table 5 examines this prospect – through equation (7) or its input equivalent – by showing the mean annual percent change in the indicated output's or input's value share induced by any twisting of the frontier. In no category has such a technical-change bias been evident at a magnitude much greater than 1%. That is, technical progress in both output and input dimensions has come in the form of virtually Hicks-neutral parallel frontier shifts. Thus also, the non-government sources driving most of the technology change have not materially favored one sector over another.

If policy, then, has had a hand in the perennial crop sector's superior technical growth, it has been the liberalized price and trade environment that has encouraged crop exporters to import foreign technology, the "informal channels" in the first RHS term of equation (12). Export weakness at the mid-1980s start of the export-led strategy were a key factor in perennial crops' relatively high technical growth since then, because the lower is perennial base output in our dataset, the higher a given absolute growth will be in the proportional terms in which technology growth (12) is measured. This is consistent with the Hicks-neutral perennial-vs-annual frontier shifts we have observed, as low base outputs are conducive to high proportionate growth even when possibility sets shift parallel. The 2.1/0.7 ratio of perennial- to annual-crop factor-constant output growth in the 1985 – 2005 period is, in other words, consistent with the relatively low prices and high trade barriers facing agriculture at the beginning of that period. It is the decline in those barriers, rather than research policy, that appears to be the chief explanation for perennials' relative production surge.

Weighting the three sector-level growth rates (2.19% in perennials, 1.70% in livestock, and 0.67% in annual crops) by the sectors' mean farm revenue shares (22.4%, 10.6%, and 67.0%, respectively) gives an aggregate technology growth rate of 1.12%. By comparison, Suhariyanto and Thirtle's (2001) 1965 – 1996 Malmquist-index study of agricultural productivity growth in 18 Asian countries found annual Indonesian technical growth to have been 0.63%.

Technical Efficiency

Twenty of the 22 provinces produced, with the same resources, at least 90% of the output achieved in the most efficient provinces. They operated, that is, within a 90-to-100 percent efficiency band of the best-practice frontier. The average province was 96% technically efficient, producing with the same resources 96% of that achievable on the frontier.[4] Annual efficiency *change* in Indonesia has averaged a rather low -0.38% per annum. Provinces with improving efficiency relative to their 1985 starting-points were, table A4 shows, Aceh and to a lesser extent Jambi, aided primarily by rapid growth in palm oil production. Appendix table A4 lists efficiency levels, and their annual (1985-2005) mean rates-of-change, by province.

Table 6 shows that provinces with higher road densities evince, as we expected, lower inefficiency error variance – and thus higher mean technical efficiency – than do those with lower road densities. The sign, size, and confidence interval of this equation (10) effect are robust to specification and time-period changes. Boosting road density one percent reduces error variance 0.63 percent. As equation (5) and Appendix B show, if mean effects on error variance of non-road-density, non-literacy factors are negligible, this corresponds to an extremely modest $-\exp[f(\ln \mathbf{z})/2]\left(-0.63/2\right)$ = 0.01 percent rise in mean technical efficiency.[5]

Human capital policies have a much greater impact on agricultural efficiency, although in a direction some may not have expected. To wit, provinces with higher literacy rates display lower productive efficiency. Improving the literacy rate by one percent exacerbates error variance by 23.8 percent and – assuming mean non-road, non-literacy effects are about zero – reduces national mean technical efficiency by 0.37 percent (that is, $-\exp[f(\ln \mathbf{z})/2]\left(23.8/2\right)$ = -0.37).

Summing the average annual technology growth rate of 1.12% and mean annual efficiency improvement of -0.38% gives a mean 1985 – 2005 per-annum Indonesian agricultural productivity growth rate of 0.74%. This rate is the net effect of technological progress and a mildly increasing disparity between frontier and average-province production. In their Malmquist study, Suhariyanto and Thirtle (2001) report by comparison a 1965 – 1996 annual Indonesian agricultural TFP growth rate of 0.17%. Fuglie's (2009) Tornqvist-Theil index approach yields a 1961 – 2006 average TFP growth of 1.8%.

Conclusions

The Indonesian government's turn, a quarter of a century ago, toward an industrial and export-led development strategy coincided with comparatively high productivity growth in perennial crops, used largely for export. That coincidence cannot, however, be explained by government research efforts, as most new perennial-crop technology – particularly in the vital oil palm industry – have originated from private sources. Nor can it be explained by perennial-crop-biased technology advances, as technology growth in fact has been Hicks-neutral in both inputs and outputs. Export's superior productivity performance therefore can be accounted for only by comparatively low mid-1980s production volumes which, as innovation diffused, were able to grow at proportionately higher rates than could annuals or livestock. Initially low export production was consistent with the early 1980s' over-valued exchange rates and other export disincentives, which were gradually lifted in the ensuing decades.

Greater openness to foreign markets also explains the non-government origin of most new agricultural technology in Indonesia. Most new plant varieties have been purchased, or obtained as international spillovers, by producers and processors incentivized through increased trade opportunities. International agricultural research centers have figured prominently on the annual-crop side of those spillovers. The failure of the Indonesian government's own research system might stem from its low and unstable funding and youthfulness, as it essentially had to be built from scratch after the 1970s. Rural education policy has impaired rather than enhanced farm efficiency, probably by encouraging newly educated workers to depart for urban areas. Nevertheless, aggregate farm efficiency remains rather high, the majority of provinces producing at least 90% of maximum output at sample-mean factor levels.

References

Aigner, D. J., C. A. K. Lovell, and P. Schmidt. 1977. "Formulation and Estimation of Stochastic Frontier Production Function Models." *Journal of Econometrics* 6: 21-37.

Alston, J., P. Pardey, and R. Piggott. 2006. Synthesis of Themes and Policy Issues, ed. P. Pardey, J. Alston, and R. Piggott. Washington, D.C., International Food Policy Research Institute (IFPRI).

Alvarez, A., C. Amsler, L. Orea, and P. Schmidt. 2006. "Interpreting and Testing the Scaling Property in Models Where Inefficiency Depends on Firm Characteristics." *Journal of Productivity Analysis* 25: 201-212.

Antle, J. M., and S. M. Capalbo. 1988. An Introduction to Recent Developments in Production Theory and Productivity Measurement, ed. J. M. Antle, Capalbo, S.M. Washington, D.C., Resources for the Future, pp. 17-95.

Battese, G., and T. Coelli. 1995. "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics* 20: 325-332.

Calderón, C., and L. Servén. 2004. "The Effects of Infrastructure Development on Growth and Income Distribution." WPS3400, World Bank, Washington, D.C.

Caudill, S. B., J. M. Ford, and D. M. Gropper. 1995. "Frontier Estimation and Firm-Specific Inefficiency Measures in the Presence of Heteroscedasticity." *Journal Of Business & Economic Statistics* 13, no. 1: 105-111.

Economic Research Service (ERS), U.S. Department of Agriculture (USDA). 2000. International Crises and Agriculture. WRS-99-3. Washington, DC: Economic Research Service (ERS), U.S. Department of Agriculture (USDA).

Evenson, R., and K. Fuglie. Forthcoming. "Technology Capital: The Price of Admission to the Growth Club." *Journal of Productivity Analysis*.

FAO. 2009. FAOSTAT Agricultural Databases. Food and Agricultural Organisation (FAO). Rome.

Färe, R., and D. Primont. 1995. *Multi-Output Production and Duality: Theory and Applications*. Boston, London, and Dordrecht: Kluwer Academic Publishers.

Fuglie, K. O. 2004. "Productivity Growth In Indonesian Agriculture, 1961-2000." *Bulletin of Indonesian Economic Studies* 40, no. 2: 209-225.

Fuglie, K. O. 2009. "Sources of Growth in Indonesian Agriculture." *Journal of Productivity Analysis*. *Online First,* September 16.

Fuglie, K. O., and R. R. Piggott. 2006. Indonesia: Coping with Economic and Political Instability, ed. P. G. Pardey, J. M. Alston, and R. R. Piggott. Washington, D.C., International Food Policy Research Institute, pp. 65-104.

Greene, W. H. 2005. "Fixed and Random Effects in Stochastic Frontier Models." *Journal of Productivity Analysis* 23: 7-32.

Huffman, W. E., and R. E. Evenson. 2006. "Do Formula or Competitive Grand Funds Have Greater Impacts on State Agricultural Productivity." *American Journal of Agricultural Economics* 88, no. 4: 783-798.

Huffman, W. E., and R. E. Evenson. 1993. *Science for Agriculture*. Ames: Iowa State University Press.

Hulten, C. 2000. National Bureau of Economic Research. "Total Factor Productivity: A Short Biography."

Jatileksono, T. 1987. *Equity Achievenment in the Indonesian Rice Economy*. Yogyakarta, Indonesia: Gadjah Mada University Press.

Kumbhakar, S. C., and C. A. K. Lovell. 2000. *Stochastic Frontier Analysis*: Cambridge University Press.

Lovell, C. A. K., S. Richardson, P. Travers, and L. L. Wood. 1994. *Resources and Functionings: A New View of Inequality in Australia, W. Eichhorn (ed.) Models and Measurement of Welfare and Inequality*. Berlin: Springer.

Meeusen, W., and J. Van den Broeck. 1977. "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error." *International Economic Review* 18, no. 2: 435-444.

Shephard, R. W. 1953. *Cost and Production Functions*: Princeton Universtiy Press.

Shephard, R. W. 1970. *Theory of Cost and Production Functions*: Princeton Universtiy Press.

Simar, L., C. A. K. Lovell, and P. Vanden Eeckaut. 1994. Institut de Statistique, Univeriste Catholique de Louvain. "Stochastic Frontiers Incorporating Exogenous Influences on Efficiency." Discussion Paper no. 9403.

Suhariyanto, K., and C. Thirtle. 2001. "Asian Agricultural Productivity and Convergence." *Journal of Agricultural Economics* 52, no. 3: 96-110.

Timmer, C. P. 2004. The Road to Pro-Poor Growth: The Indonesian Experience in Regional Perspective, Center for Global Development, Working Paper Number 38.

U.S. Department of Agriculture (USDA), Foreign Agricultural Service, Production Supply and Distribution Database. 2008.

van der Eng, P. 1996. *Agricultural Growth in Indonesia since 1880: Productivity Change and Policy Impact since 1880*: St. Martin's Press, Inc.

Wang, H. J. 2002. "Heteroscedasticity and Non-Monotonic Efficiency Effects of a Stochastic Frontier Model." *Journal of Productivity Analysis* 18: 241-253.

World Bank. 2008. World Development Indicators On-Line. Washington, DC: World Bank. Accessed March, available at http://publications.worldbank.org/subscriptions/WDI/WDI.html.

Yee, J., W. E. Huffman, M. Ahearn, and D. Newton. 2002. Sources of Agricultural Productivity Growth at the State Level, 1960-1993, ed. V. E. Ball, Norton, G.W., Kluwer Academic Publishers, pp. 185-209.

Table 1. Agricultural research spending in Indonesia in 1997-1998

Figures in 1999 international (PPP) dollars	Food Crop, Livestock, Horticulture, and Fisheries Research	Plantation Crop Research
Agricultural GDP (billion PPP$)	70.6	17.5
AARD research expenditures (million PPP$)	144.3	64.9
Private-sector research expenditures (million PPP$) ^	12.3	6.0
AARD research expenditures/Agricultural GDP	0.204%	0.373%
Private research expenditures/Agricultural GDP	0.017%	0.034%
AARD research expenditures/scientist (‘000 PPP $)	45.8	151.3

^Private-sector research expenditures are for 1996 and from Pray and Fuglie (2002).
Source: Fuglie and Piggot (2006).

Table 2. Indonesian Agricultural Commodities

Annuals	rice, corn, soybeans, peanuts, pulses, cassava, sweet potatoes, potatoes, green beans, cabbages, carrots, chilies, cucumbers and gherkins, eggplants, garlic, shallots, pumpkins and squash, spinach, tomatoes, swamp cabbage, and tobacco.
Perennials	avocados, bananas, mangos, oranges, papayas, pineapples, fruit n.e.s. (not elsewhere specified), dried coconut, palm oil, cocoa beans, coffee, tea, natural rubber, cane sugar, primary fiber crops, cinnamon, cloves, nutmeg and mace and cardamoms, pepper (white and black), and vanilla.
Livestock	cattle meat, buffalo meat, horse meat, poultry meat, sheep meat, goat meat, pig meat, cow milk, and hen eggs.

Table 3. Regularity Statistics

Monotonicity

Outputs		*Inputs*	
$\frac{\partial TF}{\partial \ln Y_{Annuals}}$	0.59	$\frac{\partial TF}{\partial \ln X_{Capital}}$	-0.18
$\frac{\partial TF}{\partial \ln Y_{Livestock}}$	0.23	$\frac{\partial TF}{\partial \ln X_{Materials}}$	-0.69
		$\frac{\partial TF}{\partial \ln X_{Labor}}$	-0.06

Convexity

Hessian Principal Minors	*Determinant*
1	0.439405
2	0.118280
3	-0.049901
4	0.027774
5	0.011661

Table 4. Technical Change Rates

	Informal Technical Change Rates (TCR)	*Output elasticity of agricultural research*	*Time rate change in agricultural research*	*Formal TCR*	*Total TCR*
Perennials	2.176%	0.002%	6.48%	0.015%	2.12%
Livestock	1.69%	0.002%		0.012%	1.70%
Annuals	0.67%	0.001%		0.005%	0.67%

Table 5. Output and Input Biases of Technical Change

<u>Inputs</u>	<u>Bias</u>
Capital	-0.06%
Materials	0.92%
Labor	-0.42%
<u>Outputs</u>	
Annuals	0.28%
Perennials	-0.35%
Livestock	-0.66%

Table 6. Decomposing Technical Inefficiency

Dep. Var.: $\ln \sigma^2_{u,it}$	*Coefficients*	*P>|Z|*
Constant	-109.554	0.000
Road	-0.632909	0.001
Literacy	23.82014	0.000

Appendix A. Data and Estimates

Table A1: Data Sources

Series	Level of aggregation	Source (see below for full citation)
Commodity production	Provincial	Ministry of Agriculture
Agricultural land use	Provincial	Central Statistics Bureau (a)
Persons employed primarily in agriculture	Provincial	Central Statistics Bureau (a)
Adult literacy rate in rural areas	Provincial	Central Statistics Bureau (a)
Agricultural machinery in use (four sizes of tractors, mechanical threshers)	Provincial	Central Statistics Bureau (a)
Farm animals in stock	Provincial	Ministry of Agriculture
Fertilizer use ^	Provincial	FAO, Central Statistics Bureau (c), Ministry of Agriculture
Farm level commodity prices	National	FAO
Farm wages	Regional	Central Statistics Bureau (d)
Fertilizer prices	Regional	Central Statistics Bureau (e)
Farm machinery rental rates	National	Derived from FAO farm machinery import prices *
Farm animal prices	National	Derived from FAO live animal import prices *
Public agricultural R&D expenditures	National	Agency for Agricultural Research and Development (a), (b), and (c)
Public agricultural research staff	Provincial, by institute	Agency for Agricultural Research and Development (a), (b), and (c)
Road density (km per km^2 area)	Provincial	Central Statistics Bureau (a)

^ Fertilizer use statistics (in tonnes of N, P_2O_5 and K nutrients) are available at the national level from FAO but information on their regional distribution is limited. Central Statistics Bureau (c) gives annual fertilizer application rates per hectare for rice and secondary food crops at the regional level. We applied these application rates to provincial-level data on crop area harvested from the Ministry of Agriculture to derive total fertilizer applied to food crops. We allocated the remaining fertilizer based on the provincial share of crop area in non-food (plantation) crops.

* We use the same derivation methods as in Fuglie (2009).

Agency for Agricultural Research and Development (a). Annual Issues 1987-1990. Organization, staffing, facilities and budget. Badan Penelitian dan Pengembangan Pertanian, Departmen Pertanian Republik Indonesia, Jakarta.

Agency for Agricultural Research and Development (b). Annual Issues 1991-1997. Pocket book: Organization, resources and research program, 1993. Badan Penelitian dan Pengembangan Pertanian, Departmen Pertanian Republik Indonesia, Jakarta.

Agency for Agricultural Research and Development (c). Annual Issues 1999-2005. Agricultural research statistics: Resources, program and research results. Badan Penelitian dan Pengembangan Pertanian, Departmen Pertanian Republik Indonesia.

Central Statistics Bureau (a). Annual Issues 1985-2005. *Statistical Yearbook of Indonesia*. Badan Pusat Statistik, Jakarta.

Central Statistics Bureau (b). Various issues. *Agricultural Indicators*. Badan Pusat Statistik, Jakarta.

Central Statistics Bureau (c). Various issues, *Farm Cost Structure of Paddy and Secondary Food Crops*. Badan Pusat Statistik, Jakarta.

Central Statistics Bureau (d). Various issues. *Farm Wage Statistics in Rural Areas*. Badan Pusat Statistik, Jakarta.

Central Statistics Bureau (e). Various issues. *Producer Price Statistics of the Agricultural Sector in Indonesia*. Badan Pusat Statistik, Jakarta.

FAO (Food and Agriculture Organization of the United Nations). 2005. FAOSTAT Agricultural Databases. Food and Agricultural Organization, Rome, Italy (July 2005).

Ministry of Agriculture. Agricultural Statistical Database, Departmen Pertanian Republik Indonesia, Jakarta. Accessed June 2007. Available at http://database.deptan.go.id/bdsp/index-e.asp.

Table A2. Indonesian Regions and Provinces

Regions	*Provinces*				
Sumatra	Aceh	North Sumatra	West Sumatra	Riau (including Riau Islands*)	
	Jambi	Bengkulu	Lampung	South Sumatra (including Bangka-Belitung*)	
Java/Bali	Bali	Central Java	Yogyakarta	East Java	West Java (including Banten*)
Sulawesi	Central Sulawesi	North Sulawesi (including Gorontalo*)	South Sulawesi	South East Sulawesi	
Kalimantan	West Kalimantan	Central Kalimantan	South Kalimantan	East Kalimantan	
E. Indonesia	Nusa Tenggara Barat (NTB)	(Because of insufficient data, Nusa Tenggara Timur, Maluku, North Maluku, Papua and West Papua provinces in E. Indonesia and DKI Jakarta in Java are not included in the analysis)			

* During 1985-2005, these provinces were created by splitting them off from existing ones. We combined the data from these provinces with their parent provinces to ensure consistent geographical units.

Table A3. Distance Frontier Parameters

Dep. Var.: -Perennials	*Coefficients*	*Standard Error*	*Z*	*P>|Z|*
t	-0.0353992	0.00618	-5.73	0
Annuals	0.7092243	0.039982	17.74	0
Livestock	0.1372314	0.030639	4.48	0
Capital	-0.144071	0.060046	-2.4	0.016
Materials	-0.3781988	0.057608	-6.57	0
Labor	-0.122332	0.069044	-1.77	0.076
R	-0.0080012	0.001778	-4.5	0
t^2	0.0002318	0.000414	0.56	0.575
Annuals^2	0.2197027	0.079243	2.77	0.006
Livestock^2	0.1746341	0.052207	3.35	0.001
Capital^2	-0.1071976	0.199788	-0.54	0.592
Materials^2	-0.3268803	0.095924	-3.41	0.001
Labor^2	0.1960565	0.260095	0.75	0.451
Capital·Materials	-0.1615038	0.130251	-1.24	0.215
Capital·Labor	-0.062629	0.195905	-0.32	0.749
Materials·Labor	-0.1491721	0.146285	-1.02	0.308
Annuals·Livestock	-0.1875911	0.052252	-3.59	0
Annuals·Capital	-0.2590672	0.109513	-2.37	0.018
Annuals·Materials	-0.0594486	0.077127	-0.77	0.441
Annuals·Labor	0.0027578	0.107603	0.03	0.98
Livestock·Capital	0.2320002	0.10296	2.25	0.024
Livestock·Materials	0.0902941	0.070276	1.28	0.199
Livestock·Labor	0.0642349	0.100683	0.64	0.523
t·Annuals	0.0052277	0.003586	1.46	0.145
t·Livestock	-0.001038	0.002962	-0.35	0.726
t·Capital	0.0076228	0.006636	1.15	0.251
t·Materials	0.0174358	0.005449	3.2	0.001
t·Labor	0.0039839	0.006908	0.58	0.564
t·R	0.0006897	0.000217	3.19	0.001

Table A4. Mean Technical Efficiency (T.E.) by Province and Year

Provinces	*Provincial Mean T.E. Levels, 1985-2005*	*Provincial Mean T.E. Changes, 1985-2005*	*Years*	*National Mean T.E. Levels, 1985-2005*
Bali	99.67%	-0.030%		
C. Java	99.22%	-0.063%	1985	97.66%
Yogyakarta	99.75%	-0.011%	1986	97.21%
E. Java	99.73%	-0.027%	1987	97.74%
W. Java	97.81%	-0.313%	1988	97.42%
Dista Aceh	96.95%	0.049%	1989	97.64%
N. Sumatra	94.50%	-0.246%	1990	97.47%
W. Sumatra	95.35%	-0.268%	1991	97.36%
Riau	94.00%	-0.239%	1992	97.06%
Jambi	96.00%	0.026%	1993	95.99%
S. Sumatra	94.43%	-0.560%	1994	96.14%
Bengkulu	95.86%	-0.163%	1995	95.69%
Lampung	96.17%	-0.049%	1996	95.30%
W. Kalimantan	97.28%	-0.633%	1997	95.96%
C. Kalimantan	86.66%	-1.957%	1998	97.09%
S. Kalimantan	95.45%	-0.860%	1999	95.20%
E. Kalimantan	90.75%	-1.151%	2000	95.61%
C. Sulawesi	93.42%	-0.739%	2001	96.75%
N. Sulawesi	89.85%	-1.769%	2002	94.81%
S. Sulawesi	99.47%	-0.036%	2003	93.39%
SE. Sulawesi	97.38%	-0.108%	2004	91.72%
NTB	99.81%	-0.024%	2005	90.44%
National Mean T.E. Level, 1985-2005	95.89%		National Mean T.E. Change, 1985-2005	-0. 38%

Endnotes

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[1] Here and in the remainder of the paper, AARD is taken to include every research institute under its authority, including the plantation crops institutes of the Indonesian Planters Association for Research and Development (IPARD). Although financed separately and quasi-independent, IPARD has formally been under AARD oversight since 1979. Forestry research, however, was separated from AARD in 1983, followed by fisheries research in 2001 when separate Ministries were established for these two sectors (Fuglie and Piggot 2006).

[2] Dummy variables are optimal for efficiency measurement only when the heterogeneity these dummies are meant to model in the time-invariant unobserved error v_{it} is itself not efficiency-related (Greene 2005). An example would be in which cross-province policy differences are accounted for by the dummies, while missing information about soil quality and pesticide differences is captured by the inefficiency error term.

[3] The two-stage approach tends to reduce multicollinearity arising when strongly trending variables are involved in the technology and efficiency estimation. However, it increases the potential for missing-variable bias.

[4] The 95.6 % confidence interval for national mean efficiency is (0.95, 0.96).

[5] At sample means, scalar $-\exp[f(\ln \mathbf{z})/2]$ = -0.031.