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THE ECONOMICS OF PEST AND PRODUCTION MANAGEMENT IN SMALL-HOLDER COCOA: LESSONS FROM SULAWESI

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We examine pest control and production management methods used by farmers in Sulawesi to improve cocoa bean quality and increase income from cocoa. Strategies investigated include those directed at increasing the number and size of cocoa pods, those aimed at reducing hosts for pest transmission, two input-intensive approaches, and the alternative of doing nothing beyond harvesting mature cocoa pods. Using 2005 production data from 600 cocoa farms, we identify factors correlated with adoption of each treatment and, controlling for treatment, isolate factors that influence cocoa yields. To study the conditional profitability of input allocation, we compare observed factor shares with profit-maximising input levels and derive lessons for extension efforts. We conclude that the average increase in private returns arising from more intensive cocoa management appears sufficient to compensate for higher production costs, but that observed extension efforts have not been correlated with higher profits among farmers in the sample.

INTRODUCTION

Cocoa trees thrive in tropical climates, and 90% of cocoa is produced by smallholders on farms less than five hectares in size (ICCO 2008). Approximately 70% of world cocoa supply comes from West Africa. During the 1990s Indonesia rapidly expanded production and is now the third-largest producer after Côte d'Ivoire and Ghana, producing slightly more than 400,000 tonnes in 2004–05. Of Indonesia's cocoa, 70% – nearly one-tenth of the world's supply – is grown in Sulawesi.

The development and potential long-term viability of Sulawesi's cocoa sector has received considerable attention, beginning with the work of Jamal and Pomp (1993) and continuing with the more recent analyses of Neilson (2007) and Ruf and co-authors (for example, Ruf, Ehrut and Yoddang 1996; and Ruf and Yoddang

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1998, 2001, 2004). Shapiro and Rosenquist (2004) discuss the important and ongoing role of the private sector in facilitating the sustainability of the cocoa industry, and Akiyama and Nishio (1997) describe the policy environment for cocoa in Sulawesi. Nearly all of these observers stress that one of the main threats faced by Indonesia's cocoa farmers at present is infestation by a moth (*Conopomorpha cramerella*) known as the cocoa pod borer (CPB). CPB infestation in Indonesian cocoa was confirmed in 1997 by Matlick (1998), and the industry estimates that infestation in Sulawesi adversely affects up to 80% of cocoa farms (Neilson et al. 2005). If infestation occurs when the cocoa pod is ripe, near harvest, most of the beans in the pod remain unaffected. However, if infestation occurs when the pod is immature, its entire contents can be lost. Unfortunately it is often difficult to detect the presence or severity of infestation.

Large production losses have serious implications for farmers, processors and manufacturers of chocolate.[1] Industry observers estimate production losses due to infestation in Sulawesi to be approximately $300 million annually (Shapiro et al. 2008). Furthermore, relatively little is known about the physiology of the CPB moth and how best to control it. CPB has now spread throughout the islands of Indonesia, and has recently appeared in Papua New Guinea (CABI 2006).

Despite industry arguments that there is a profit incentive to control CPB and other pests and diseases, infestation rates and yield losses remain significant. This pattern is widely blamed on lack of information, lack of training in control methods, and problems with maintaining quality incentives along the supply chain. Accordingly, our analysis is motivated by an interest in how farmers differentially respond to perceived cocoa problems, depending on – among other things – the degree and method of their exposure to local extension services. We investigate three questions. First, given reported farm problems, what explains patterns of production practices, especially techniques to resolve or address cocoa production problems? Second, are the techniques farmers use to improve cocoa quality and reduce pest infestation working? And third, have cocoa extension services been associated with increased profitability for farmers? Given the importance of the CPB problem and the likely spread of CPB to other production locations in Southeast Asia, our goal is to generate findings that will be relevant to farmers in Sulawesi and in other locations in Indonesia and beyond.

FRAMEWORK

Our initial empirical aim is to identify factors correlated with choice of technique. We then ask whether the techniques chosen influence cocoa yields and profitability. Our underlying assumptions are that farmers are motivated by profits and can respond to problems from a menu of available interventions. Individual choices will reflect a range of resource constraints and expected outcomes. To measure the likelihood of a particular response, we use a multinomial logit (MNL) model, a multiple outcome model in which outcomes are not ordered (Borooah 2001). Our MNL model measures the likelihood of a behavioural response given conditioning

1 Neilson (2007) argues that declines in quality are largely a problem for the domestic processing industry, since US and European grinders have found ways to adapt to low-quality beans.

factors such as household and farm characteristics. The response groups are formed such that one response is not found in any of the other response categories. This model can be motivated by a framework in which one assumes that a decision maker will choose options that will maximise expected profit (Greene 2000). Given that our focus is cocoa – a cash crop that has no subsistence value to the household – the assumption of profit maximisation seems appropriate.

To formalise the model, we denote choices by θ, characteristics by x and profits by π. A farmer will choose option j over option k if $prob(\pi_j) > prob(\pi_k) \forall k \neq j$, that is, if the probability of profit for option j is larger than the probability of profit under option k, for all values of k that are not equal to j. Following Greene (2000) and Gensch and Recker (1979), this MNL model for adoption can be written as:

$$prob(\theta_i = j) = \frac{e^{\beta' x_{ij}}}{\sum_{j=1}^{n} e^{\beta' x_{ij}}}, \quad j = 1, 2, \ldots n$$

where the equations provide an exhaustive set of probabilities for the plot-level responses in which one possible choice is compared to all others. In the empirical section we examine five such categories of response for cocoa farmers. The results from these regressions are of interest in their own right for what they reveal about patterns of behaviour. But we also employ the MNL model to provide a set of instrumenting regressions for our categories of response, retaining for subsequent analysis the predicted probabilities for each farmer-choice combination. Equipped with these predicted probabilities of response, we then estimate a set of cocoa yield regressions, subsequently incorporating the instrumented choice probabilities as control variables. We do this to explain observed yields in the sample, controlling for the latent characteristics of adopters. We ask whether, once one has controlled for farmer characteristics, extension exposure and the self-reported farm-specific problems that precipitated behavioural responses, observed yields are correlated with available treatments and data on farmer exposure to project and extension efforts. Furthermore, since farmers are interested in profits and not just yields, we investigate the profit-maximising levels of inputs in the sample and assess the possible impact of extension efforts on profits.

DATA

Study location and characteristics of cocoa farms

Our data come from Noling Village in Luwu district, 325 kilometres north of Makassar, the capital of South Sulawesi province. The island of Sulawesi is home to an estimated 400,000 cocoa-producing families. This site, occupying approximately 12 square kilometres, was chosen because of the severity of its CPB infestation, and the involvement, beginning in 2003, of the Pest Reduction, Integrated Management (PRIMA) project aimed at educating and training farmers in pest control for cocoa.[2] The site is divided into nine blocks based on natural borders

2 The PRIMA project is a joint initiative of Masterfoods Veghel BV and PSOM (Program of Cooperation with Emerging Markets), funded by the development cooperation budget of the Netherlands Ministry of Foreign Affairs.

TABLE 1 *Characteristics of Cocoa-growing Households in the Sample*

Variable	Sample Average
Buginese ethnicity (%)	98
Muslim (%)	99
Age of household head (years)	48
Primary school completion by household head (%)	35[a]
Number of household members	4.8
Farm size (ha)	2.0
Farm ownership (1 = owned, 0 otherwise) (%)	96
Labour use (%)	
Family labour only	78
Hired labour	22
Any family members working off-farm	18
Number of households	**600**

[a] The most frequently reported educational attainment was 'primary school attendance but not completion'.

Source: The source for all tables is the authors' survey data.

and existing neighbourhoods. Eight blocks (A–H) are covered by the PRIMA project. The other block (I) lies outside the PRIMA project site and serves as a control. Data on household characteristics, production and input use were collected for production year 2005.

Descriptive data for 600 households and 915 cocoa fields are provided in tables 1 and 2. All sample farmers grew cocoa on at least one field. Additionally, 269 farmers reported a second cocoa field, 40 reported a third field and six reported a fourth. The average size of the primary cocoa field was 1.16 hectares. The additional fields were somewhat smaller on average. Land tenure in the area, despite being insecure *de jure* for a range of historical reasons, is considered secure *de facto* by most farmers: 96% of the sample reported field 'ownership', which in this case reflects a perceived right to farm the land. Average total farm size is slightly less than two hectares, and most households (78%) manage their own farms without the use of hired labour. The sample consists almost exclusively of Buginese, a group widely known for cocoa production (Li 2002).

A one-hectare cocoa field can accommodate 800–1,000 trees with 3m x 3m spacing. We find fairly uniform spacing in our sample. Non-producing or dead trees account for 20% of all trees, on average.[3] The average tree age in the sample is 18 years, and the average production level is 832 kg/ha.[4] Purchased input use is

3 Sample farmers do not seem to be replacing unproductive trees at a high rate: data indicate one new tree is planted for every two trees that are deemed unproductive.

4 Estimated coefficients from a regression of yield on age and age squared suggest that cocoa production in the sample appears to peak at a tree age of approximately 22 years. Although cocoa trees can remain productive for much longer than this under ideal conditions, old trees are not typical in the growing area.

TABLE 2 *Characteristics of Cocoa Production among Sample Farms*

Description	Sample Average
Number of producing trees per hectare	850
Number of non-producing trees per hectare	172
Field distance from residence (km)	0.7
Farm size (ha)	2.0
Tree age (years)	18
Production level (kg/ha/year)	832
Full sun production	823
Shade production	856
Fertiliser used (kg/ha/year)	457
Pesticide used (litres/ha/year)	1.6
Herbicide used (litres/ha/year)	3.0
Family labour used (person days/ha/year)	55
Hired labour used (person days/ha/year)	23
Profit (Rp 1,000/ha/year)[a]	9,648
Number of cocoa plots	**915**

[a] During the survey year (2005) the average rupiah/dollar exchange rate was 9,721, with a low of 10,802 and a high of 9,064. For computation of profit, we impute the cost of family labour using the market wage.

ubiquitous in the sample and we observe relatively frequent use of hired labour, including occasional outside management of a family's cocoa plots.[5] Cocoa farmers harvest pods throughout the year, but two harvest periods predominate: a main crop from mid-October through November and a mid crop from late April through June. The average pod carries 40–60 beans, and each bean contains approximately one gram dry weight (2.6 grams if wet). Farmers dry beans for roughly two days before selling them to a local trader, a collection centre or up-country buying station, or an input supplier.[6]

The majority of farmers in the sample depend heavily on income from cocoa for their livelihoods. On average, 69% of the total household income of survey respondents comes from the sale of cocoa beans; a number of farmers in the sample also grow coconut, rice, cloves and local fruits for cash. The majority of households rely on family labour; 22% of households hire labour. Over 80% of sample farms own sprayers for the application of pesticide, fertiliser or herbicide. Tools

5 The use of outside management is a potential complicating factor in the analysis, but we observe relatively few instances in which the family relinquishes complete oversight of the farm to an outside party. Instead, the use of contracted spraying and fertilising seems to be the most regular form of outside management. We cannot reject the hypothesis that average yield and average profit are equivalent on contractor-managed and owner-managed plots, although we recognise that this may be due to the relatively small number of contractor-managed plots in the sample.

6 In general, Indonesian cocoa farmers do not ferment cocoa beans, because the beans are valued mainly for butter content, which is unaffected by fermentation (Neilson 2007).

TABLE 3 *Main Cocoa-growing Problems Reported by Sample Farmers*

Reported Problem	% of Farmers Reporting
Cocoa pod borer	56
Old trees	16
Black pod disease	7
Soil infertility	7
Stem canker	3
Poor overall maintenance	2
Other	9
Number of farmers reporting	**600**

needed for cocoa production include pruning shears, harvesting poles with sharp hooks, and machetes for opening cocoa pods. The majority of the sample, 73%, reported having one or more of these agricultural tools.

Factors affecting cocoa production and farmer behaviour

Our survey data identified factors perceived to limit income generation from cocoa production. Survey participants were asked to rank problems adversely affecting cocoa production and quality. Farmers with multiple fields provided separate rankings for each field. Farmers reported 23 distinct production problems, ranging from pests and diseases to ageing trees, poor soil fertility and rodent damage. Table 3 lists the primary problems most frequently reported in the sample. More than half of all farmers perceived CPB as their primary cocoa-related problem.

The dependent variable for the MNL model is derived from a survey question about the farmer's reported field-level response to the perceived primary problem limiting cocoa profitability on that field. Using both pre-determined categories and an open-ended format, the survey recorded 51 different responses, many of them thematically related. For the purposes of the MNL model, these 51 responses were grouped into one of five categories: (1) *growth* (applied to 15% of fields, and requiring, on average, 70 annual person days of labour per hectare), that is, techniques to promote the growth of healthy trees, including use of fertiliser, grafting and tree rehabilitation; (2) *cleaning* (13%, 74 days), comprised of techniques to promote a sanitised field, including pruning, sanitation and spraying (as a combined effort), removing and burying infested pod husks, raking excess leaf litter and removing infested pods; (3) *spraying* (24%, 90 days), identified as the use of pesticides with no other strategy or technique; and (4) *spray plus* (18%, 94 days), the most labour-intensive response, which includes spraying pesticide in combination with use of fertiliser, pruning and/or regeneration practices. The final category, (5) *other* (30%, 61 days) includes no specific action, or a technique that was idiosyncratic and not easily categorised; of the responses categorised in '*other*', 73% correspond to no course of action.

The independent variables used in the MNL model are defined in table 4. The final column of the table provides each variable's frequency in the sample (as a percentage). Binary location variables (A, B … I) are included to control for unobservable block-specific factors and network effects. Key variables identifying reported problems are used to control for the likelihood of correlation between a

TABLE 4 *Variables Used in the Multinomial Logit Model*

Variable	Description	% of Sample
Response	*Growth*	15
	Cleaning	13
	Spraying	24
	Spray plus	18
	Other (serves as base case)	30
Block location	A	17
	B	17
	C	6
	D	6
	E	7
	F	17
	G	9
	H	14
	I (non PRIMA farmers)	8
Other variables		46
CPB	1 if CPB = primary farm problem, 0 otherwise	
Old trees	1 if old trees = primary farm problem, 0 otherwise	20
Age of head	1 if below 48 (sample average), 0 otherwise	53
Education of head	1 if completed primary school, 0 otherwise	35
Motor cycle	1 if HH owns motor cycle, 0 otherwise	49
Multiple fields	1 if HH manages multiple fields, 0 otherwise	34
Sprayer	1 if HH owns sprayer, 0 otherwise	81
Agricultural tools	1 if HH owns other agricultural tools, 0 otherwise	72
Training	1 if HH completed 4+ field schools, 0 otherwise	55
Demonstration plot	1 if HH visited demonstration plot, 0 otherwise	19
Visits	1 if HH was visited by PRIMA staff, 0 otherwise	32
Free inputs	1 if HH received free inputs, 0 otherwise	10
Non-cocoa income	1 if HH has non-cocoa cash income, 0 otherwise	46

[a] HH = household.

particular response and an identified problem. Household characteristics, including asset variables, are included to account for household-specific factors in the behavioural responses. Finally, we include several project-related variables (for example, training) to assess the impact of the PRIMA project on farmer behaviour and outcomes. The PRIMA project trained farmers primarily in methods to improve productivity and bean quality. These methods included frequent harvesting, pruning, sanitation and fertilisation. In addition, PRIMA maintained eight demonstration plots to disseminate alternative farming techniques to farmer groups and leaders. One of the issues we explore below is whether exposure to the PRIMA project conferred benefits on farmers within the project catchment.[7]

7 For additional information about the PRIMA project, see Neilson et al. (2005).

RESULTS

Behavioural responses to cocoa problems

Results from the MNL regressions are presented in table 5. Results are listed for each of four response categories: *growth*, *cleaning*, *spraying* and *spray plus*. The fifth response category, *other* (in 73% of cases amounting to doing nothing other than harvesting), is the base case. All statistical results are interpreted in comparison to this response.

Looking across all columns of table 5, we find a scattering of relatively strong block effects. Observations are grouped into nine blocks, and all coefficients can be interpreted relative to block H. Non-significant coefficients can be considered to be zero (i.e. no different from block H). Location-specific coefficients are statistically significant in 17 of 32 cases. Although we cannot observe the factors correlated with these spatial differences, in all likelihood they reflect differences in soil conditions, pest or disease spillovers, and network effects among households in particular blocks. Patterns suggest that, overall, farmers in the non-PRIMA area (block I) tended to respond to problems at a higher rate than farmers in the PRIMA blocks, the non-PRIMA block being the only group for which the response coefficient is positive and significant across all four response categories. Moreover, for almost all responses except those in the *spray plus* category, the non-PRIMA block has a higher coefficient than the PRIMA blocks. The sole exception is *spraying* in block D. Overall, therefore, we conclude that PRIMA farmers were less likely than their cohorts in the non-PRIMA block to undertake activities aimed at promoting cocoa tree growth, or to carry out cleaning or spraying. This is somewhat surprising, since the extension services were intended precisely to encourage farming practices of this kind. Below, we explore this point further in the context of yields and profitability.

Focusing attention on the CPB variable, we see that if CPB was identified as the primary cocoa problem, farmers were more likely, on average, to respond through *cleaning*, *spraying* or *spray plus* activities. In contrast, when old trees were perceived by farmers to be the primary limiting factor in production, a farmer was more likely to respond with growth-enhancing interventions and was far less likely to spray. Farmers with multiple fields were less likely to spray, perhaps indicating labour constraints for this time-intensive activity among farmers managing multiple fields. Ownership of a back-pack sprayer is positively correlated with spraying, as expected, but not with other activities. Ownership of other agricultural tools (including, but not limited to, knives and cutting and trimming tools) is correlated with a higher proportion of responses in the cleaning category. In short, we find, not surprisingly, that farmers' responses are closely correlated with what they perceive to be their major problems, and with their ownership of particular kinds of equipment.

Four explanatory variables in the MNL model (training, demonstration plot, free inputs and visits) are related to specific aspects of the PRIMA project. Several interesting patterns emerge with respect to these variables. First, we find that those farmers who attended four or more of the eight farmer field school (FFS) training sessions were more likely to adopt growth-oriented interventions than to do nothing. This is not surprising, given that many of the field school sessions focused on promoting technologies to enhance the growth of cocoa trees and increase yields (for example, side grafting, tree rehabilitation and regeneration, and pruning).

TABLE 5 *Results for Multinomial Logit Model*

Variable	Category of Response			
	Growth	*Cleaning*	*Spraying*	*Spray Plus*
Constant	–2.96*	–1.94*	–1.58*	–3.80*
	(5.61)	(3.54)	(2.97)	(4.32)
Block A	0.214	0.807*	–0.507	2.25*
	(0.39)	(1.73)	(1.11)	(2.80)
Block B	1.39*	0.065	0.454	–0.346
	(3.42)	(0.13)	(1.04)	(0.34)
Block C	1.04*	0.263	–0.530	2.71*
	(2.13)	(0.46)	(0.83)	(3.22)
Block D	1.18*	–0.737	1.70*	4.08*
	(1.91)	(0.65)	(2.80)	(4.63)
Block E	1.32*	0.739	–0.158	2.45*
	(2.12)	(1.18)	(0.26)	(2.76)
Block F	0.711	–0.015	0.341	2.31*
	(1.46)	(0.03)	(0.80)	(2.89)
Block G	1.07*	–0.128	–1.33*	–2.00
	(2.35)	(0.26)	(2.59)	(1.53)
Block I (non-Prima)	2.73*	1.31*	1.15*	2.31*
	(4.95)	(2.20)	(2.08)	(2.51)
CPB	–0.321	1.75*	2.48*	3.01*
	(0.82)	(5.72)	(8.80)	(8.50)
Old trees	0.961*	–0.475	–2.14*	–0.221
	(3.63)	(1.30)	(4.19)	(0.48)
Age of head	0.390	–0.063	–0.261	–0.312
	(1.63)	(0.25)	(1.13)	(1.21)
Education of head	–0.080	–0.379	–0.331	–0.001
	(0.33)	(1.48)	(1.41)	(0.00)
Number of fields	–0.100	–0.380	–0.492*	–0.051
	(0.42)	(1.53)	(2.12)	(0.20)
Motor cycle	–0.157	–0.013	0.031	–0.118
	(0.63)	(0.05)	(0.13)	(0.45)
Sprayer	0.427	–0.255	0.999*	0.098
	(1.48)	(0.85)	(2.93)	(0.28)
Agricultural tools	0.164	0.823*	0.095	0.169
	(0.62)	(2.68)	(0.36)	(0.57)
Training	0.748*	0.151	–0.060	0.026
	(2.63)	(0.55)	(0.24)	(0.09)
Demonstration plot	–0.288	0.094	–0.759*	–0.803*
	(1.10)	(0.34)	(2.58)	(2.41)
Visits	0.440	0.714*	0.874*	0.911*
	(1.59)	(2.54)	(3.31)	(3.17)
Free inputs	–0.498	0.057	–0.023	0.908
	(1.32)	(0.13)	(0.06)	(1.60)
Non-cocoa income	–0.014	0.026	0.081	–0.228
	(0.06)	(0.10)	(0.35)	(0.86)
Pseudo R^2	0.24			
Log likelihood	–1,082.9			
No. of observations	136	119	169	221

[a] Omitted response category is '*Other*' (n = 270) and includes 'no response'. Absolute values of *t*-statistics are in parentheses. An asterisk (*) indicates that the estimated coefficient is significantly different from zero at the 90% confidence level or greater.

Participation in FFS training had no obvious correlation with other behavioural responses in the sample. Farmers who had participated in field visits to PRIMA demonstration plots were less likely to respond to problems with *spraying* or *spray plus* activities. In part, this may reflect the role of demonstration plots in providing farmers with better information to help them identify pest and disease problems, and thereby avoid unnecessary use of chemical inputs. An alternative explanation is that farmers with an enhanced ability to identify pest and disease problems would also be able to use chemicals in a more focused and informed attempt to overcome those problems. Training at the demonstration plots did not necessarily discourage pesticide use, but rather encouraged proper, prudent and safe use of agricultural chemicals. Those who reported being frequently visited by PRIMA staff were more likely to adopt active responses other than growth-oriented activities (which were addressed in the FFS setting). Such one-on-one contact with project staff raised the likelihood of response above that for farmers who did not receive frequent visits. We can see no obvious explanation, however, for the curious result that the signs on the coefficients for *spraying* and *spray plus* are negative in relation to visits by farmers to demonstration plots but positive in relation to visits to farmers by PRIMA staff. Finally, somewhat surprisingly, farmers who reported having received some of their inputs free of charge from the PRIMA project did not display higher rates of response in any category.

Cocoa yields

We now turn to a set of three Cobb–Douglas production functions to identify factors correlated with yields. The results are reported in table 6. Where appropriate, independent variables have been scaled to per-hectare amounts. Models are estimated in log–log form. Model 1 is a short regression that includes location variables and input levels; model 2 adds indicators for farmers' self-reported cocoa problems; and model 3 includes the predicted probabilities for each response category. To repeat, after estimating the MNL model, we generated these predicted probabilities for each farmer–response combination. For each field these predicted probabilities sum to one and provide in-sample predictions of adoption for each response.[8]

Model 1 focuses attention on the influence of location, physical input use and tree age on yield. We find a small number of block-specific differences in yield. Importantly, despite the fact that the MNL model indicated generally higher response activity in the non-PRIMA area, evidence that farms outside the PRIMA project site have significantly different yields from those within the project site is generally weak and mixed. For example, a simple comparison of outcomes inside and outside the PRIMA project site suggests differences in cocoa yields; the mean yield within the project area (836 kg/ha/yr) exceeds the mean outside the project

8 Viewed in terms of a two-stage least squares (2SLS) regression, the four PRIMA project variables included in the MNL regression serve in conjunction with the farmer characteristic variables (age and education) to identify the response variables for inclusion in the yield regressions. We have assumed that the influence of the project on outcomes worked solely through the indirect pathway of influencing choice of response, and had no direct impact on yields. Test results for endogeneity and over-identification restrictions are not reported here, but are available upon request.

TABLE 6 *Results for Yield Regressions*

Variable	Yield (kg/ha/yr)		
	Model 1	Model 2	Model 3
Constant	0.478*	0.443	0.303
	(1.74)	(1.62)	(1.01)
Block A	0.274*	0.192	0.202
	(2.29)	(1.51)	(1.17)
Block B	–0.324*	–0.331*	–0.395*
	(2.87)	(2.92)	(2.81)
Block C	0.039	0.048	–0.004
	(0.25)	(0.32)	(0.02)
Block D	0.167	0.128	–0.237
	(1.05)	(0.80)	(1.07)
Block E	0.298*	0.215	0.146
	(1.95)	(1.36)	(0.75)
Block F	0.307*	0.249*	0.102
	(2.56)	(1.96)	(0.67)
Block G	0.109	0.086	0.284*
	(0.80)	(0.62)	(1.71)
Block I (non–PRIMA)	–0.016	–0.070	–0.138
	(0.11)	(0.48)	(0.76)
Fertiliser used (kg/ha)	0.030*	0.028*	0.028*
	(4.50)	(4.18)	(4.08)
Pesticide used (litres/ha)	0.030*	0.029*	0.027*
	(3.87)	(3.77)	(3.46)
Herbicide used (litres/ha)	0.003	0.007	0.008
	(0.36)	(0.98)	(1.10)
Family labour used (days/ha/yr)	0.394*	0.389*	0.392*
	(15.37)	(15.22)	(15.34)
Hired labour used (days/ha/yr)	0.235*	0.233*	0.232*
	(11.11)	(11.03)	(11.04)
Tree age (years)	7.64*	7.82*	7.93*
	(5.88)	(6.02)	(6.12)
Tree age^2 (years^2)	–3.30*	–3.39*	–3.46*
	(5.24)	(5.40)	(5.49)
CPB	–	0.252*	–0.113
		(0.62)	(0.57)
Old trees	–	0.138	0.257*
		(1.47)	(1.86)
Response: *growth*	–	–	0.158
			(0.36)
Response: *cleaning*	–	–	–0.578
			(0.99)
Response: *spraying*	–	–	0.972*
			(2.45)
Response: *spray plus*	–	–	0.883*
			(1.70)
R^2	0.58	0.58	0.59
No. of observations	915	915	915

[a] Absolute values of *t*-statistics are in parentheses. An asterisk (*) indicates that the estimated coefficient is significantly different from zero at the 90% confidence level or greater. Plot-level yields are measured in natural log of kilograms per hectare per annum.

area (733 kg/ha/yr). However, a two-sample *t*-test (t = 1.40) fails to support the hypothesis that yields are statistically different at standard test levels. Yield differences appear to be limited to block-by-block patterns. Block comparisons based on the estimated coefficients for the models reported in table 6 suggest that yields in three blocks (A, E and F) tended to be higher than those in the reference block (H), and yields observed in one block (B) were lower. Yields in the non-PRIMA block (G), did not differ from those in the reference block (H).

Input–output relationships follow the expected patterns, with all inputs positively correlated with yield, and all correlations (with the exception of herbicides) statistically significant.[9] Family and hired labour are both important inputs, with comparable – and statistically indistinguishable – impacts on yield, on average. Our measure of tree age indicates a positive correlation between age and yield, at least up to the peak production age of approximately 22 years (see footnote 4).

For model 2 we add to model 1 binary variables for the top two cocoa problems identified by respondents: CPB and old trees. The results from model 1 are robust to the inclusion of these variables, with relatively little change in magnitude or statistical significance across the regressions. Although a substantial percentage of the sample farmers perceive old trees to be their primary on-farm problem, model 2 provides no empirical support for the view that farmers who identify old trees as a primary problem have below-average production levels. Despite farmers' perceptions, those who report old trees as a problem tend to have higher yields, on average, than those who do not, although the coefficient is not statistically significant.[10] One important and curious result from model 2 is the fact that the estimated coefficient for CPB is positive and significant. On the face of it, this suggests that the presence of CPB results in higher yields, which is highly implausible. We believe the explanation for this pattern is that farmers who recognise CPB problems are responding to the risk of infestation in appropriate and effective ways, while those who fail to perceive and act on this problem suffer lower yields as a result.

Evidence in support of this conjecture can be found in the results from model 3, which adds to model 2 the instrumented probabilities of farmer response. Again, the basic patterns in the yield regression remain robust to the inclusion of these variables. Two important exceptions emerge, however. First, the coefficient on the 'old tree' variable increases in magnitude and becomes significant, indicating

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9 As an anonymous reviewer pointed out, the positive association of pest infestation with yields is probably due to the fact that farmers with pests are responding to the problem effectively. On the other hand, in separate regressions not reported here we find a relatively weak correlation between herbicide use and profits. This may or may not be evidence that herbicide use is unprofitable, as the weak correlation may be attributable to the fact that herbicides are used in response to severe weed infestations. In the absence of a measure of weed infestation, herbicide use can be a proxy for the intensity of weed infestation. Therefore it should not immediately be concluded that herbicides have no effect on yields or profitability.

10 Given that the average tree age is 18 years, which is less than the 22-year optimum (see footnote 4), our results do confirm that farmers with trees older than 22 years obtain less than optimum yields, as do those with younger trees. Nevertheless, those who own the older trees face a problem of declining yields and are therefore justified in their concern, whereas those who own younger trees will not face this problem for some time.

that, controlling for farmer behavioural response, those who perceive that their problem rests with the age of their trees are actually performing better than average. This suggests that these farmers may be under-estimating the yield advantage associated with having mature trees. Second, the correlation between CPB and yield becomes insignificant when we include a farmer's response information. This provides evidence that model 2 probably over-estimates the importance of perceived problems, owing to the omission of the behavioural responses, which we include in model 3. Most importantly, the responses that are most highly and significantly correlated with cocoa yield are the most intensive practices associated with spraying. On average, if we control for location, input use and cited problems, farmers who engage in these practices report above-average yields. *Spraying* appears to provide a slightly greater yield advantage than *spray plus*, although a hypothesis that the estimated coefficients are the same cannot be rejected. Overall, these results suggest that, on average, farmer interventions through spraying seem to be compensating for CPB infestation. Although many farmers perceive their problem to be old trees, there is no evidence that the yields of this group of farmers are significantly different from the sample average.

Cocoa profitability

What matters to the farmer is profit. Therefore, to augment the results of the yield regressions, we now examine cocoa profitability in the sample. The most basic comparisons, based on a set of two-sample *t*-tests for differences in annual cocoa profits per hectare, indicate statistically similar profits inside and outside the PRIMA project sites (Rp 9.6 million vs Rp 10.1 million; $t = 0.94$); somewhat higher (but again statistically similar) profits among those who received project training than among those who did not (Rp 12.0 million vs Rp 9.5 million; $t = 1.20$); and significantly higher profits among those who reported contact with PRIMA staff (Rp 13.0 million vs Rp 8.8 million; $t = 3.93$). Taken together, these results provide only modest support for the conjecture that extension efforts were correlated with higher cocoa profits.

One simple way to assess whether farmers' observed levels of profitability reflect optimising behaviour, in the context of a Cobb–Douglas production function, is to compare observed factor shares with profit-maximising factor shares, where the latter can be derived from the yield regression equation, recognising that the first-order necessary condition for profit maximisation requires the marginal value product of each input to equal its marginal cost. So, for example, if we let β_i represent the coefficient on the i^{th} input and let S_i represent this input's share in the value of production – that is, the ratio of payments to this input divided by total revenue from sales – profit maximisation simply requires that $\beta_i = S_i$.[11] Furthermore, $(\beta_i - S_i)$ is equal to the potential increase in profits, expressed as a percentage of the total revenue from sales, that would accompany a 1% increase in the use of input *i*.

To measure these differences, we work with our preferred yield regression (model 3 in table 6) and employ the estimated production function coefficients in

11 Let π be profit, Y output, P the price of output, X_i the quantity used of input i and W_i the price of input i. Then $\partial\pi / \partial X_i = P\partial Y / \partial X_i - W_i$. Therefore $\left[\partial\pi / PY\right] / \left[\partial X_i / X_i\right] = \beta_i - W_i X_i / PY$.

TABLE 7 *Departures from Optimal Input Use*

Input	β_i (optimal input share)	S_i (observed revenue share)	$\beta_i - S_i$	Increase in Profit from Rp 1,000 More Spent on Input
Average for all farms				
Family labour	0.392	0.153	0.239	1,562
Hired labour	0.232	0.042	0.190	4,524
Fertiliser	0.028	0.003	0.025	8,333
Herbicide	0.008	0.020	–0.012	–600
Pesticide	0.027	0.032	–0.005	–156
Average for non-PRIMA farms				
Family labour	0.692	0.172	0.520	3,023
Hired labour	0.309	0.150	0.159	1,060
Fertiliser	0.043	0.016	0.027	1,688
Herbicide	0.018	0.013	0.005	385
Pesticide	0.046	0.028	0.018	643

conjunction with sample-average values for input levels, cocoa revenue and input and output prices, valuing household labour at the market wage. Our computations are presented in table 7, where we also show the estimated potential increase in profit that could be obtained by increasing spending on each input by Rp 1,000. We present results both for the sample average and for non-PRIMA farmers specifically. The results indicate that, at the sample average for all farms (the top panel of table 7), optimal input shares (measured by β_i) for herbicides and pesticides are less than the observed revenue shares (measured by S_i), indicating over-use of these inputs. For labour, the results indicate that farmers are using significantly less than the optimal amounts of both family and hired labour. However, it is important to keep in mind that we impute the value of family labour using the market wage, and hence the estimated value of revenue share for family labour depends on the arbitrary assumption that its opportunity cost is the same as the cost of hired labour. If one sums across all factor-specific revenue shares, we find that approximately 25% of annual cocoa revenues are being paid to the non-land, non-tree factors of production; in other words, 75% of the revenue accrues to the owners of the fixed factors – land and trees – over and above the assumed opportunity cost of family labour.[12]

Focusing on the sub-group of non-PRIMA farmers alone (the lower panel of table 7), we find that approximately 38% of annual cocoa revenues are being paid to the non-land, non-tree factors of production and the remaining 62% accrue to the owners of the fixed factors, land and trees. In other words, farmers in the

12 Of course if the assumed opportunity cost of labour were higher, the apparent profit forgone would be correspondingly lower.

PRIMA blocks appear to be enjoying somewhat higher returns to land and trees. Outside the PRIMA site, the potential returns to all inputs are positive.

CONCLUSIONS AND POLICY IMPLICATIONS

Our analysis reveals that the behavioural responses of cocoa farmers to perceived production problems in Sulawesi can be traced to a range of observable factors, including location, identified problems, ownership of specific assets, and access to information (including extension project resources). Significant positive yield differentials are associated with adopting responses in two of the four categories studied here (*spraying* and *spray plus*). Evidence suggests that spraying is a profitable response, even though it is a relatively labour-intensive management strategy and involves a large set of environmental and farmer health concerns that we cannot address directly in the context of this paper. Approximately 42% of the sample adopted a spraying strategy of some kind. This shows that a large proportion of farmers in the sample are actively engaged in efforts to manage CPB and other production problems, and are managing them in a profitable way.

From a policy perspective, farm profitability is a key consideration. From an extension viewpoint, providing guidelines for optimising input use seems important. Our analysis of profitability sheds light on both issues and suggests that, for the average farmer in the sample, modest gains in profit could be realised through greater use of fertiliser, and of both household and hired labour. Some evidence suggests that there is modest over-use of pesticides and herbicides from an economic perspective, at least within the larger sub-sample of PRIMA farms.

Results from the MNL model suggest a pathway by which improved production practices could be achieved: the number of visits from project staff is positively correlated with adoption of CPB control treatments. Moreover, farmers who communicated with project staff had significantly higher profits per hectare than those who did not. We believe from this evidence that extension efforts may be an effective way of addressing the needs of farmers and reducing CPB-related losses. However, we find no strong evidence that average profits within the project area were significantly higher than profits outside the project area. Moreover, the non-PRIMA farms exhibit stronger responses in three categories of activity. Given that the PRIMA and non-PRIMA groups are equally profitable, on average, this evidence suggests that extension services are probably not being targeted in a way that is increasing profitability (unless, of course, one's counter-factual belief is that farmers in the PRIMA blocks were far worse off than those outside the PRIMA area before the project, an assertion that we cannot test).

If new and existing demonstration plots focus on ways to reduce CPB infestation, analysis of progress and effectiveness should also be disseminated to farmers. However, moderately strong location effects uncovered in the adoption and yield regressions indicate that the effectiveness of treatments may be site specific. While our data do not allow us to identify these site-specific features of the landscape, the latter probably include soil and micro-climate conditions and localised pest and disease pressures. This spatial finding implies that multi-location testing and flexible tailoring of treatment recommendations to specific sites may enhance both technology adoption and outcomes. It also indicates that successful control and dissemination strategies might be based on identifying relatively successful farmers to serve as leaders in extension and education efforts. We also point out that the overall variance of adoption outcomes cannot be completely explained by our regressions. The location specificity of treatment efficacy and the variability in farmer response suggest that a more nuanced analysis, taking into account farmers' risk attitudes and cash constraints, may be of value.

An overall policy implication that arises from this analysis is that extension visits appear to facilitate adoption of effective pest management strategies. However, we cannot conclude that these efforts have translated into appreciably higher on-farm profitability. For this reason, we believe that extension efforts should be examined closely. A case could be made for examining the benefits and costs of increased investment in delivery of extension services to cocoa farmers, especially because our results do not reveal measurable differences in outcomes inside and outside the extension project site. Such a benefit–cost analysis has not been undertaken here, because it requires quantifying all of the benefits arising from extension, including the potential gains in adoption arising from extension, and comparing them with the budgetary costs of delivering those interventions, costs that we do not observe. If undertaken, such an analysis should also account for any potential spatial or temporal spillover effects of improved pest management. Finally, although the sample studied here is probably broadly similar to farmer populations in other cocoa-growing areas of Sulawesi, we make no strong claims to the sample's representativeness of all cocoa-producing regions of the country. Given the importance of the cocoa sector to Indonesia, expanded analysis along geographic and thematic lines seems warranted.

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