TECHNOLOGY ADOPTION, RESOURCE MANAGEMENT, AND EFFICIENCY IN THE INDONESIAN SHRIMP INDUSTRY

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ABSTRACT

TECHNOLOGY ADOPTION, RESOURCE MANAGEMENT, AND EFFICIENCY IN THE INDONESIAN SHRIMP INDUSTRY

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As the second largest producer in the world, shrimp aquaculture plays an important role in the Indonesian economy, particularly in the economies of rural coastal communities. Aggregate production statistics demonstrate that shrimp aquaculture production is increasing rapidly, and this expansion is due largely to the intensification of production practices via the use of a new shrimp HYV (high-yield variety). However very little is known regarding (1) which farmers are constrained in adopting the HYV and the complementary feed technology; (2) the effect HYV diffusion on mangrove forests, and; (3) the efficiency of agricultural traders in the dynamic shrimp industry.

These gaps in knowledge are addressed by the following: (1) chapter 1 examines the adoption of HYV and shrimp feed among household aquaculture farms. Results show that while there are no farm-scale barriers to adopting HYV, small farms are constrained in full intensification via the adoption of feed; (2) chapter 2 explores the impact of HYV diffusion on the rehabilitation of mangrove forests. Results show that HYV diffusion increases the probability that villages will replant mangrove forests to mitigate erosion; (3) chapter 3 examines the factors determining allocative inefficiency among trader in the shrimp value-chain. Results show that there are efficiencies of scale, and that institutional arrangements affect allocative ability.

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Introduction

As the second largest producer in the world (FAO, 2013), shrimp aquaculture plays an important role in the Indonesian economy, particularly in the economies of rural coastal communities. Since commercial introduction of the shrimp HYV in 2004, national statistics show that production of the HYV has gone from zero in 2004 to nearly double the quantity of the traditional variety by 2011, while production of the traditional variety has flat-lined over the same period. This demonstrates that the shrimp industry is growing quickly and is being driven by adoption of HYV.

However, very little is known regarding (1) who has been included in the growth of the industry via the adoption of HYV and who has been constrained in participation; (2) the sustainability of farming system intensification and the environmental impact of HYV diffusion, and; (3) the efficiency of agricultural traders that intermediate the development of the industry. The objective of this study is to address each of these topics.

The first chapter examines the inclusion of smallholders in the growth of the shrimp aquaculture industry in Indonesia. This study utilizes data from a survey of 1000 shrimp aquaculture farmers in Indonesia to test for farm-scale effects in the adoption of shrimp HYV and formulated shrimp feeds: two critical technologies that are driving intensification of production systems and growth in the shrimp industry. Results show that: (1) there is no farm scale effect in the adoption of HYV, but; (2) after adopting HYV, farms that were less than 0.5 hectares were constrained in the adoption of shrimp feed.

The second chapter explores the impact of HYV diffusion on the management of mangrove forests in coastal communities. Population pressure and farm expansion have led to severe mangrove loss and much of Indonesia's coastlines are barren and exposed to the risk of erosion. Recognizing the important erosion mitigating function of mangroves, communities are beginning to rehabilitate lost forests. This study utilizes data from a survey of 75 coastal villages in Indonesia to test if the rate of HYV diffusion in the village is affecting the village's propensity to replant mangroves. Results show that HYV diffusion significantly increases the likelihood that a village will rehabilitate mangrove forests. This means that intensification of farming systems and conservation of the environment are not mutually exclusive objectives. Some technologies, such as the HYV shrimp, can induce positive outcomes on natural resources.

The third essay explores the determinants of allocative inefficiency among shrimp traders in Indonesia. This study utilizes data from a survey of 200 shrimp traders in Indonesia to estimate a stochastic cost frontier to analyze the allocative performance of shrimp traders. Results show that the most efficient firms are (1) larger in scale; (2) socially networked with people with downstream agents; (3) contracted to a downstream agent, and; (4) specialized in trading only one type of shrimp.

Chapter 1: Modern variety adoption and intensification in Indonesian shrimp aquaculture: Are small farmers included?

1.1 Introduction

Long neglected in development literature, policy attention is beginning to focus on the role of aquaculture in poverty reduction and economic growth (Smith et al., 2010), with particular concern for smallholder farms (Belton et al., 2012). While small farms played the central role in the Green Revolution in Asia (Mellor, 1976), the role of small farms in the development of modern globalized agriculture industries, such as aquaculture, is under debate (Wiggins et al., 2010). Some argue that small farms will be excluded in modern agriculture due to restricted access to proprietary production technologies, and constraints in making lumpy investments (Byerlee et al., 2009; Collier, 2008); but studies are finding that smallholders are included when (1) production is still dominated mainly by smallholders; (2) farms own requisite non-land assets, or; (3) if procurement systems rely on traditional wholesale markets (Reardon et al., 2009; Swinnen, 2007).

The primary objective of this paper is to identify if smallholders are participating in the growth of the shrimp aquaculture industry in Indonesia, a modern globalized agriculture sector that is characterized by (1) bi-modal size distribution of farms — at one end is a large mass of small household farms, and at the other end are large intensive farms like members of "Shrimp Club of Indonesia" and CP Prima, the largest shrimp operation in the world; (2) heterogeneity in the endowments of important non-land assets, and; (3) modern procurement systems that are regulated by international trade standards.

We study smallholder inclusion by testing for farm-scale effects in the adoption of shrimp HYV and the adoption of formulated shrimp feeds, critical inputs that are driving intensification of production systems and overall growth in the shrimp industry of Indonesia.

As the second largest producer in the world (FAO, 2013), shrimp aquaculture plays an important role in the Indonesian economy, particularly in the economies of rural coastal communities. Farmer productivity in Indonesia is, however, among the lowest in the world with average annual aquaculture output around 1MT per farmer, compared with 4 in India, 7 in China, 35 in Chile and 187 in Norway (FAO, 2012). The low-productivity of farms combined with strong potential for development are reasons behind a Presidential Decree that prioritized intensive expansion in the country's shrimp industry and permitted commercial import of shrimp HYV (high-yielding-variety) in 2004.

The shrimp HYV (*litopenaeus vannamei*) is native to the waters of Central America and has been specifically bred to exhibit superior traits compared to the traditional variety (*penaeus monodon*): (1) it is resistant to known shrimp pathogens; (2) has increased tolerance to high stocking densities, and; (3) is more efficient at converting shrimp feed into meat mass. Since commercial introduction of the shrimp HYV in 2004, national statistics show that production of the HYV has gone from zero in 2004 to nearly double the quantity of the traditional variety by 2011, while production of the traditional variety has flat-lined over the same period (Figure 2). This demonstrates that the growth of the shrimp industry hinges on the diffusion of HYV and the resultant intensification of farming systems.

Following the varietal choice, farming system intensity depends on the adoption of formulated feed. Without using shrimp feeds, farms rely only on the naturally occurring biota in the pond ecosystem (plankton, algae) as the nutrient source, which limits production to the low natural carrying capacity of the pond's ecosystem. The adoption of feed allows farms to add an artificial nutrient source and intensify production systems beyond the low capacity of natural systems.

What remains unknown is to what extent household farms are participating in HYV adoption and to what extent they are adopting formulated feed to intensify production systems and participate in the growth of the Indonesian shrimp aquaculture industry.

While the adoption of HYV in staple crops has been extensively studied in the Green Revolution literature (Feder et al.at, 1985; Hayami & Kikuchi, 2000), very little is known regarding the adoption of aquaculture technology such as shrimp HYV. Briggs et al. (2004) has documented the diffusion of shrimp HYV at aggregate national levels, Ha et al. (2013) observed that HYV adoption was occurring among households in Vietnam, but nothing is known regarding the household decision to adopt the shrimp HYV or adopt shrimp feed. In contrast, studies in shrimp aquaculture have focused primarily on analyzing the productivity of the traditional shrimp variety (Gunaratne & Leung, 1996; Sharma & Leung, 2003), and the HYV (Yu & Leung, 2010). We address this gap in the literature by modeling the HYV and feed adoption decisions among shrimp aquaculture households.

Shrimp aquaculture technology adoption decisions can be stylized in a simple technology adoption tree diagram (Figure 3) where the adoption of HYV and feed occur in sequence: (1) HYV adoption choice followed by; (2) feed adoption choice. Thus, all shrimp farms fall into one of four categories of technology adoption. From least to most productive, they are: (1) Traditional farmer that does not use feed; (2) Traditional farmer that has adopted feed; (3) HYV farmer that does not use feed; (4) HYV farmer that has adopted feed.

These four technology categories represent what can be characterized as four constrained equilibriums or “poverty traps” (Barrett & Swallow, 2006). Poverty trap literature has focused on the adoption of agricultural innovations, participation in modern markets (Barrett, 2008), and institutions (Barnett et al., 2008). This study adds to this previous work by characterizing four constrained equilibriums and identifying the factors keeping households constrained in each of the low-productivity traps or causing households to leap to higher-productivity equilibriums. We focus primarily on farm-scale and capital as potential factors constraining farms in low-productivity traps. The specific research questions we focus on are as follows:

(1A) What is the effect of farm-scale on the propensity to adopt HYV?

(1B) What is the effect of farm-scale on the propensity to adopt feed?

These questions arise in response to a common belief among policy-makers that the adoption of aquaculture HYV and feed is isolated only to large corporate farms, with the exclusion of household farms. Empirical evidence from studies of staple crop HYVs have shown that small farms are not constrained in HYV adoption, however, empirical evidence of small-holder exclusion in the adoption of external inputs (fertilizer and pesticide) have been mixed (Feder et al., 1985). We add to previous work and debate by testing scale effects in the context of shrimp aquaculture, in the adoption of shrimp HYV and shrimp feed.

(2A) What is the effect of asset endowments on the propensity to adopt HYV?

(2B) What is the effect of asset endowments on the propensity to adopt feed?

A common constraint to increasing productivity is the capital holdings of the household. The essence of a low-productivity trap is that households are unable to self-finance investments needed to achieve higher productivity (Barrett & Swallow, 2006). Intensifying shrimp aquaculture often requires important capital items like water pumps as prerequisites to accommodate the HYV and feed intensive production systems. In this study we test if capital is a constraint to the adoption of these shrimp technologies.

(3) Are the adoption functions for shrimp feed the same for HYV adopters and non-adopters?

Finally, the constraints that bind a household in a particular low-productivity trap may be different from the factors binding a household in a different trap. While farm-scale may be barrier for traditional farmers in adopting feed, it may not be a constraint for HYV farmers. We test if the constraints to feed adoption are the same across all varieties or if they are specific to each.

To test these hypotheses, this study uses a unique and detailed dataset of the author's own survey of 1000 shrimp farm households in Indonesia.

The rest of the paper proceeds in the following sections: (2) Theoretical Model; (3) Household Survey Data; (4) Model Specification and Hypotheses; (5) Estimation Method; (6) Descriptive Statistics; (7) Regression Results; (8) Summary and Conclusions

1.2 Theoretical Model

To model the adoption of HYV and feed, we begin with a model of a household farm maximizing utility as presented by Sadoulet & Janvry (1995). It is a non-separable household utility model with credit and market failures, where households derive utility from consumption (c) and choose farm technology (elements of vector x).

1.2.1 The household's optimization problem

The household derives utility from the consumption of goods, c. We adapt the utility function so that it also depend on household characteristics, H, to account for household level heterogeneity in the utility function. The objective of the household is to maximize this utility function by allocating factor inputs, x.

$$\max_x u(c, H)$$

The household is constrained by a number of conditions:

(i) $\sum_{i \in T} p_i(x_i + E_i - c_i) + S \geq 0$, cash constraint for tradable goods (T)

(ii) $\sum_{i \in TC} p_i(x_i + E_i - c_i) + R \geq 0$, constraint for traded goods subject to credit (TC)

(iii) $f(x, k) = 0$, a production technology

(iv) $p_i = \overline{p_\iota}$, i $\in T$, an exogenous market price for tradable goods

(v) $c_i = x_i + E_i, i \in NT$ an equilibrium condition for non-tradables (NT)

Where x>0 represents a good (shrimp) produced, and x<0 represents factor inputs used such as PL, shrimp feed, and labor. E is the household initial endowment, which includes the endowment of labor. S is the net transfers received, such as remittance income. R is access to credit for goods that can be purchase on credit. $\overline{p_\iota}$ is the market price vector that the household faces at the time the household chooses vector x. K is the vector of fixed capital such as water pumps and pond area. H is the vector of household characteristics, for example household size, household education, and age.

1.2.2 Solutions

From the constrained optimization problem stated above, Sadoulet and De Janvry (1995) show that, after the manipulation of the first order conditions, the system of supply and factor demand functions that results are a function of decision prices (p^*), and fixed capital (k).

$$x^* = x(p^*, k)$$

Since the decision prices p^* are a function of the exogenous prices ($\bar{p}$), the capital endowment of the household (k), exogenous transfers (S) and access to credit (R), the reduced form estimable form of the factor demand equations (X^*) are then a function of all exogenous variables in the model.

$$X^* = X(\bar{p}, K, S, R, H)$$

For the purpose of this study, we focus on two key inputs in this system: the shrimp post-larvae variety (X_V^*); and formulated shrimp feed (X_F^*). The reduced form for the factor demand, or adoption function, for HYV and shrimp feed are expressed as:

$$X_V^* = X_V(\bar{p}, K, S, R, H)$$

$$X_F^* = X_F(\bar{p}, K, S, R, H, \sigma)$$

1.3 Household Survey Data

To answer our research questions, we use data from the authors' own survey of household farms in Indonesia outside the complex of large plantation type farms. Interviews were conducted in the months of July and August of 2010, and collected detailed information on: (1) choice of inputs used in production; (2) prices of inputs and outputs; (3) endowments of capital; (3) scale of the farm operation; (4) household characteristics, and; (5) village infrastructure. The recall data obtained from the survey of farm households allow us to construct a recall panel of two years (2007, 2009) to implement our analysis. The rest of this section discusses the design of the (1) survey instrument and; (2) the survey sample.

1.3.1 Questionnaire design & development

The development of the questionnaire took place between April and July of 2010. Pre-testing of the questionnaire was conducted as an iterative process where each questionnaire draft was tested on a range of different farm households and then revised after feedback in the field. During this stage, we iterated through 8 versions of the questionnaire and tested the questionnaire on over 30 different farmers ranging in size and production technology. The extensive testing was conducted in order to: (1) to correct confusing wording and simplify any concepts that were not readily understood by a respondent. This means using local vocabulary and restructuring questions so that farmers could answer accurately without probing; (2) to reduce the complexity of the questionnaire structure for ease of use by enumerators and reduce error in enumeration; (3) to make the questionnaire flow and transition in order to make the interview process easier to conduct; (4) edit and revise questionnaire in response to any new information acquired from pre-test respondents.

The lengthy design and development phase resulted in high response rates for variables. The response rates for the questions used to construct variables used in analysis ranged from 98% to 99% (Table 3). Out of 1000 surveyed households, 986 had complete data, which is a rate of 98.6%.

1.3.2 Sample Design

Observations were purposely drawn from the population of household level farms, having excluded MNC and corporate farms, in order to model the behavior of typical household shrimp farms found throughout Indonesia. This is done in order to see to what extent the typical household farms is contributing to the growth of the shrimp industry.

1.3.2.1 Province selection

To select the provinces in which to administer our survey of shrimp households, we set out to choose two provinces that represent the two major types of shrimp aquaculture producing provinces in Indonesia: (1) Developed and; (2) Hinter-island.

Developed shrimp aquaculture producing provinces are composed of shrimp producing regions characterized by rural communities with: (1) dense populations in rural villages; (2) good public infrastructure in canals, roads, and public utilities; (3) more developed and diversified economies with easier access to factor markets; (4) poor production conditions due to high pollution in the waters used for shrimp aquaculture.

Hinter-island shrimp aquaculture provinces are characterized by: (1) low population densities; (2) poor public infrastructure, with poor roads, deteriorated canals, and no electricity; (3) much less diversified rural economy that relies almost entirely on agricultural production; (4) ideal production conditions in the form of cleaner unpolluted waters.

We selected one province of each type to represent the two different types of shrimp producing provinces that exist in Indonesia. The provinces chosen are Central Java and South Sulawesi. The selection of these two different provinces as our study sites allows us to capture the full range of different incentives, capacities, and resultant behaviors of shrimp farming households that exist in Indonesia.

1.3.2.2 Central Java (CJ)

We choose Central Java to represent the "developed" shrimp aquaculture producing provinces of Indonesia that are typically to the island of Java, the most populated island of Indonesia.

Central Java is a province located in the center of the island of Java, and is one of the major production regions in Indonesia. The shrimp production areas of Central Java are located along the northern coast and are nearby the well-maintained major interstate highway that connects Jakarta, the primary port of Indonesia, with Surabaya, the second largest port. Rural production areas in this province are in villages that are diversified in many economic activities as these villages are integrated into the larger economy of the island of Java. However, pollution from major urban areas in and near Central Java (Semarang, Cirebon, Tegal), and pollution from the more densely populated rural have generally led to deteriorating water quality and poor production conditions for aquaculture farmers in this province.

1.3.2.3 South Sulawesi (SS)

We choose South Sulawesi to represent the “hinter-island” shrimp aquaculture producing provinces of Indonesia that are found off of the island of Java and are less densely populated compared to Java.

South Sulawesi province is located on the southwestern part of the island of Sulawesi (Celebes). The main production areas of South Sulawesi are located along the western cost of the province, and are typically near the Trans-Sulawesi highway that connects cities to the major port of Makassar, and also in the southern coast which has very poor road infrastructure. Rural economies in South Sulawesi are generally less developed compared to those found on the island of Java as these communities still revolve much more on production of agricultural commodities. Inclusion of South Sulawesi in the study allows us to model the behavior of farmers in “hinter-island” settings.

1.3.2.4 District selection

Within each selected province, we chose two districts that represent two different types of shrimp production zones: (1) Districts that are close to a major city or port; (2) Districts that are far from a major city or port. One of each type of district was selected from each province giving a total of 4 districts in our sample. This geographic variation allows us to exploit more of the differences in infrastructure conditions that may be important in the uptake of aquaculture technology.

1.3.3 Census of farm households

To generate a population listing of farmers, we conducted our own census of all shrimp-producing household within each of our selected districts. For each district, our census method proceeded in two steps:

First, we identified all villages within the district that had any shrimp farming households. Cross-checking with information from local government extension agents, the list of villages with shrimp production was compiled for each of our selected districts. Identification of these villages was straightforward as shrimp production takes place only along the coastline. The villages on the coastline with land usable for shrimp aquaculture production (land that is not rocky cliff or sand beaches) were not many and were easily identifiable.

Second, for each village on the list, a team of enumerators and supervisory staff went to each village and compiled a listing of all shrimp aquaculture farmers in the village. These listings compiled information on the names, locations, and the current HYV adoption statuses of each shrimp aquaculture farmer in the village. To make sure that the listing was accurate and up to date, these population listings were crosschecked and verified with village heads, farmer cooperative leaders, or lead farmers in the village to account for any absent households.

Table 1 show that there were 2,259 shrimp aquaculture farmers in our selected districts. Census results show a big difference between the two provinces in the rate of HYV adoption. While South Sulawesi had an overall HYV adoption rate of 4%, the adoption rate in Central Java was 37%.

1.3.4 Sampling households

To draw a sample of 1000 shrimp farming households in our districts, we conducted a stratified random sampling and over-sampled HYV adopting households in our chosen districts in order to ensure that there would be enough HYV adopting households in the survey to draw inference. We stratified the sample primarily because districts in South Sulawesi had very few HYV adopters to draw, and oversampling ensured that the few HYV adopting farms in the district would be included in the sample.

Even with the over-sampling of HYV adopters, the effect of survey design was slight. Overall, the sample design only yielded a positive 2% bias in our sampling of HYV-adopters (Table 2). Using the data from the population listings, we weight the sample back to population figures in each district for analysis. All statistics used in our analysis are weighted results.

Since the level of randomization in this survey is at the district level, interpretation and generalization of results should be confined within the bounds of our chosen districts.

1.4 Model Specification & Hypotheses

In this section, we describe the variables used to specify our model, the hypotheses to be tested, and the functional form assumptions made for estimation.

1.4.1 Dependent variables (X)

We implement our analysis of HYV adoption and shrimp-feed adoption using data gathered on household farm input use. The two dependent variables we model in our analysis is the shrimp variety (X_V) and shrimp feed (X_F). X_V is a binary variable and it takes the value of one if the household has adopted the shrimp HYV and zero otherwise. X_F is also a binary variable and it takes the value of one if the household has adopted formulated shrimp feed, and zero otherwise. Both variables are observed in two periods in the data 2009 and 2007.

1.4.2 Independent variables

Recall that the general form of the HYV adoption and input use behavioral functions are a function of prices (P), capital (K), net transfers (S), access to credit (R), household characteristics (H), and yield risk (σ). In this section we discuss how these variables are measured and discuss descriptive statistics of these variables.

1.4.2.1 Output price expectation (P_q)

To model the household's output price expectation, we use the naïve expectations approach in which the lagged output prices is used to impute the household's prediction of the output price at the time of harvest. Shrimp is a globally traded commodity. For the household farm, the only output price information available at the time of the varietal choice is the price of shrimp at that time. Naïve expectations are likely a close approximation of the heuristic used by the farm household to form the output price expectation as no other relevant information on global production and consumption is readily accessible by household farms.

The variables used in analysis are lagged village level prices of the traditional variety and HYV variety. We construct this price by calculating the village level average price[1], of one kilogram of output in the lagged period. Lastly, we divide the average village price of hired labor, which we use as the numeraire good.

[1] Lagged village level average prices are calculated by taking the average price in the village excluding household *i*. That is, the price of a good for household *i* in a given village is: $P_i = \sum_{j \neq i} \frac{P_j}{n-1}$, where *i* represents household (*i*=1,…,n), *n* is the sample size in the village, and P_j is the price reported by household j.

1.4.2.2 Input prices (P_x)

The input prices included as regressors are the observed village level prices at the time of the input choice. The input prices included are the price of post-larvae ('seed'), and the price of shrimp-feed. The input prices are also village level prices and are constructed using the same method as the output average village price. We hypothesize that households that have access to cheaper HYV inputs will be more likely to adopt HYV.

We also include the distance to the nearest hatchery from the village. This is measured by the minutes of travel time required to traverse the distance between the village and the hatchery. This variable proxies the transaction costs of purchasing post-larvae, and also proxies access to technical information regarding new production technologies. Our hypothesis is that shrimp aquaculture intensification occurs in spatial clusters where the development of input-supplying industries paves the way for farmers in its vicinity to intensify production via adoption of new input technologies. So the distance to a hatchery will likely be an important factor in determining adoption.

1.4.2.3 Household characteristics (H)

The set of variables in the household characteristics category include (1) the size of the household measured as the number of people over 16 years old. This is the household's labor endowment and it is fixed; (2) the education of the household head in years; (3) the age of the household head, and; (4) the experience of the household head, which measures the ability and knowledge of the farm household. Our hypothesis is that larger households, more educated, older and more experienced household heads will be more likely to adopt advanced farm technologies.

1.4.2.4 Remittance income (S)

We include the average monthly remittance income a household receives to indicate an exogenous shock to income. This income source may be in an important source of cash that shifts out the cash constraint and may be allowing households to fund investments into adopting new yield increasing farm technologies. This income source may also help to spread the risk of adopting a new technology. We hypothesize that households with more remittance income will be more likely to adopt HYV and feed.

1.4.2.5 Access to credit (R)

We include a dummy variable indicating the presence of a bank branch in the village. This variable serves as a proxy to measure access to formal credit and a reduction in the cost of making financial transactions with buyers and sellers. We hypothesize that the presence of a bank branch will increase the propensity for the household to adopt HYV and feed because (1) banks improve access to credit for shrimp farm households to finance the costs of adopting HYV and shrimp feed, and; (2) they ease the transfer of funds (with electronic fund transfers from traders) and reduce transaction costs of purchasing inputs and selling outputs.

1.4.2.6 Lagged land assets (K_T)

Lagged land assets are also included in the set of regressors. This vector contains variables that measure the quantity and quality of the household's land endowment in the year just prior to the HYV and feed adoption decisions. We include three measures of land assets:

First is the total pond area that the household operated. This measures the total pond area, owned or rented, that the household utilized for shrimp production at the time of the adoption decisions. Previous studies on the adoption of cropping technologies found that small farms were generally not constrained in the adoption of seed varieties (see review by Feder et al., 1985). We add to this work by testing if farm-scale is an important factor in the adoption of HYV in aquaculture, a previously unexplored production system.

Literature on the effect of farm-scale on the adoption of external inputs is less clear. Studies identifying the effect of farm-scale on the use of fertilizer and pesticides have yielded mixed results (Feder et al., 1985), and it is unclear if small-farms are participating in external-input using intensification strategies. The mixed empirical results may be due to the fact that the complementarity of land and external-inputs are unique to each crop and variety. While small-farms may be most efficient in utilizing shrimp feed for the traditional variety, perhaps large-farms are most efficient in utilizing shrimp feed for the HYV. We add to this literature by testing if the effect of farm scale on the adoption of shrimp feed, a critical external input, is unique or different across the two varieties.

Second, we include the depth of the pond as another variable in analysis. This variable measures the vertical distance from the center of the pond floor to the peak of the pond's embankment. The HYV can inhabit ponds volumetrically while the traditional variety inhabits only the pond floor, and farms with deeper ponds have additional capacity to support HYV production and the use of shrimp feed. Thus, we hypothesize that households with deeper ponds will be more likely to adopt HYV and shrimp feed.

Third, we include the total cropland operated by the household as another variable in analysis. This measures the total land area, owned or rented, that the household utilized for crop production at the time of the adoption decision. On one hand, households operating more cropland could have higher propensities to adopt because crop-farm income could be helping households manage the risk of using new shrimp aquaculture technologies. On the other hand, more cropland could mean that there is less family labor, cash, and credit available to aid farms in adopting shrimp HYV and feed.

1.4.2.7 Lagged productive capital (K_p)

Lagged productive capital endowment is also included in our set of regressors. This variable is measured by the count of water pumps the farm household owned prior to the adoption decisions. Water pumps were originally used to irrigate crops in Indonesia, pumping water from canals onto plots, but have been adapted by aquaculture farmers to circulate water in and out of ponds.

For aquaculture production, water pumps allow farmers to circulate water in and out of their ponds at any time without relying on slow tidal flows used in traditional farming systems. They improve management of: (1) water levels; (2) water exchange, and; (3) effluent buildup in pond. As aquaculture production systems intensify, management of these control points becomes more important and having water pumps to control these points is essential. However, water pumps are very expensive and can cost upwards of 400USD to purchase. Without a savings reserve, access to credit, or income from remittances, households may be constrained from investing in water pumps and adopting shrimp HYV and feed. In this study, we test to see if water pump endowments are a constraining factor in the adoption of shrimp HYV and feed.

1.4.2.8 Lagged village capital (K_v)

Two dummy variables indicating village level capital are included as regressors. First is the dummy variable indicating the presence of an extension office in the village. While most aquaculture-farming households in the sample have had some kind of contact with government extension officers, not all contact is equal. We measure the differences in the frequency and quality of these interactions with a binary variable indicating if the village office building has a permanent space (either a desk or a room) dedicated to the extension officer. Villages with a dedicated space may have more interaction and specialized support than those without a space. We hypothesize that villages with an extension office space will have a higher propensity to adopt HYV and shrimp feed.

Second is the presence of mangroves along the coast of the village at the time of the adoption decisions. Mangroves mitigate the risk of ponds being eroded into the ocean. Similar to the discussion on land tenure, the risk of land-loss will affect the household's decision in making long-term investments. In light of this, we hypothesize that the presence of mangroves on the village coastline will increase the household’s propensity to adopt HYV.

1.4.2.9 Lagged organizational capital (K_o)

A dummy variable indicating membership in a producer organization (cooperative) in is also included as a regressor. Social learning and organizations have been found to be important in the diffusion of new agricultural innovations (Conley & Udry, 2001; Foster & Rosenzweig, 1995). Producer organizations play an important part for aquaculture farmers in (1) the diffusion of market information and information regarding new technologies; (3) collective management of common-pool waterways like canals and rivers; (4) collective management of shrimp disease outbreaks by signaling diseases and coordinating water exchange; (5) the ability to purchase collectively to access input markets. In light of this, we hypothesize that membership in a producer organization increases the propensity for a household to adopt HYV and shrimp feed.

In addition, a variable indicating if the observation is related to or has social ties to early adopters (those adopting in the initial year of introduction) is also included. This measures the farmer’s access to specific knowledge regarding threshold investments, returns from varietal shift, access to markets, and other important information and relationships that are otherwise difficult to access. We expect that this social capital will have a positive effect on the adoption of HYV shrimp aquaculture technology.

1.4.2.10 Output risk (σ)

One of the major reasons that HYV was introduced to Indonesia is to mitigate the disease problems that are common in the traditional variety. To address the issue of risk, we include a measure of yield risk as measured by the lagged standard deviation of yield per hectare of the traditional variety. This variable measures the magnitude of risk that is specific to the conditions of the respondent's village. Risk in shrimp production is generally determined by the canal infrastructure, environmental, and agronomic conditions within the village. For example, villages with poorly designed or degraded canal networks tend to have higher incidences of disease outbreaks.

The farm household allocates resources having observed the yield outcomes of other households in the village in the past, not only their own outcomes, and this yield variance is specific to each village. We hypothesize that higher variance in the yield per hectare will reduce households' propensity to adopt shrimp aquaculture technologies.

1.4.2.11 Functional form

Recall that the general form of the HYV adoption (X_V) and feed adoption (X_F) behavioral functions are a function of prices (P), capital (K), net transfers (S), access to credit (R), household characteristics (H), and yield risk (σ). For simplicity of notation, we collapse these variables into one vector (Z) and leave out the variable that measures the household's pond area (T).

In specification, we make a small deviation from the conventional linear form. First, we allow micro-farms (farms that operate less than 0.5 hectares of pond area) to have a different marginal effect on the propensity to adopt HYV and feed compared to other farms. We implement this empirically by including variable M, which is observed in the following way.

$$M_{it} = T_{it}[T_{it} > 0.5]$$

Where T represents the pond area operated by the household. Given the linear approximation below, the marginal effect of pond area on X is γ for micro-farms and $\gamma + \delta$ for all other farms.

$$X_{it}^{*} = \beta Z_{it} + \gamma T_{it} + \delta M_{it} + \varepsilon_{it}$$

We do this because: (1) micro-farms are a subset of the shrimp farm household population that is of particular interest to policy makers in SE Asia due to their large population and vulnerability; (2) micro-farms are unique in that they face different access conditions to credit and input markets due to their lack of land collateral and fixed costs associate with accessing markets.

1.4.2.12 Testing for structural break in the farm-scale effect

In exploratory analysis, we allowed the structural break in the farm-scale effect to be endogenously determined in estimation. The endogenously determined breaking point occurred at 0.6 ha. This was calculated by estimating the adoption functions with structural breaks occurring at different points — the functions were first estimated with the breaking point occurring at 0.1 ha and we iterated through breaking points in 0.05 ha increments ending at 7 ha. The maximum likelihood was achieved at a breaking point of 0.6 ha, which is very close to the popular 0.5 ha size category that is commonly used by policy-makers when describing land-poor farm households.

To keep the discussion salient and relevant to the mental categorization of policy makers, we estimate the adoption functions with the structural breaking occurring at 0.5 ha, which is very close to the actual 0.6 ha endogenously determined threshold. This allows us to analyze structural differences for the micro-farm population, which is commonly identified as an important vulnerable population.

1.4.2.13 Structural difference in feed adoption behavior by variety

In addition, we allow for structural difference in the feed adoption equations for HYV adopters and non-adopters, and allow all of the model parameters to be different. We do this by modeling feed adoption in two regimes: (1) HYV adopters, X_{itA}^{*} and; (2) non-adopters, X_{itN}^{*}. The system of equations we estimate is as follows:

$$X_{itA}^{*} = \beta_A Z_{it} + \gamma_A T_{it} + \delta_A M_{it} + \varepsilon_{Ait}$$

$$X_{itN}^{*} = \beta_N Z_{it} + \gamma_N T_{it} + \delta_N M_{it} + \varepsilon_{Nit}$$

$$\mathrm{X}_{\mathrm{itV}}^{*} = \beta_V Z_{it} + \gamma_V T_{it} + \delta_V M_{it} + \varepsilon_{Vit}$$

The subscripts *i* represents households, *t* represents the year, *A* denotes HYV adoption, *N* denotes non-adoption, and V denotes variety.

1.5 Estimation Method

In this section we present the distributional assumptions, the problem of endogenous switching, and finally the estimator used for analysis.

1.5.1 Probit system of equations

To economize notation, we will collapse all covariates into our vector, Z_{it}. Given the functional forms described above, and the limited way in which we observe our dependent variables, we express the system of equations to be estimated as the equations below. Note that the feed adoption equations are expressed in two regimes: HYV adopting and HYV non-adopting. The HYV adoption equation serves as the regime switching equation. Farm households switch between the regimes following the condition below:

$$X_{V,it} = 1[\varepsilon_{V,it} \leq -Z_{it}\beta_V]$$

$$X_{F,it} = \begin{cases} 1\left[\varepsilon_{A,i} \leq -Z_{it}\beta_A\right], & if\ X_{V,it} = 1 \\ 1\left[\varepsilon_{N,i} \leq -Z_{it}\beta_N\right], & if\ X_{V,it} = 0 \end{cases}$$

Following a multivariate normal (MVN) distributional assumption, we can express the distribution of $\tilde{\varepsilon}$ as:

$$\begin{bmatrix} \varepsilon_V \\ \varepsilon_A \\ \varepsilon_N \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho_{VA} & \rho_{VN} \\ & 1 & 0 \\ & & 1 \end{bmatrix}\right)$$

Then it follows that the likelihood of observation *i* can be expressed as

$$\mathcal{L}_i(X_i, Z_i \mid \beta, \rho) = \int_{\widetilde{H}(X_i)} \phi(\tilde{\varepsilon}, \Sigma) d\tilde{\varepsilon}$$

Where $\phi(\bullet)$ represents the normal probability density function, and $\widetilde{H}(\bullet)$ represents the link function that determines the region of the density function to be integrated given that X_i is observed. Note that in this case, $\widetilde{H}(\bullet)$, indicates the six bounds of integration, two for each dimension of the MVN distribution.

Estimating using direct maximum likelihood is cumbersome and computationally intensive, as it requires the integration of the MVN distribution in multiple dimensions for each observation. In estimation, we employ a program developed by Roodman (2011) in which the likelihood of an observation is computed using the GHK MVN simulator (Geweke, 1989;

Hajivassiliou & Mcfadden, 1998; Keane, 1994), where the numeric integral of a MVN distribution is simulated using systematic random draws. The method is designed to reduce simulation noise (variance due to simulation) and reducing computational intensity.

1.5.2 Endogenous switching probits (Nested Probits)

It is possible that unobserved factors determining the HYV adoption decision could also be correlated to the unobserved factors determining feed adoption. If an unobserved factor is affecting the adoption decision of both HYV and feed, $cov(\varepsilon_V, \varepsilon_A) = \rho_{VA}$ and $cov(\varepsilon_V, \varepsilon_N) = \rho_{VN}$. If these covariances are not equal to zero, the correlation of these unobserved factors in both HYV adoption and feed adoption equations would lead to endogenous selection bias if they were to be estimated as three independent equations.

To control for endogenous selection into HYV adoption we rely on the properties of the multivariate normal distribution and allow the error term in the HYV equation (regime switching equation), to be correlated with the error terms in the feed adoption equations (regime equations) in the manner specified below. This allows for structural correlation between the unobserved factors in the HYV adoption (regime switching) equation with those in the feed adoption (regime) equations. This is an extension of the classic endogenous switching regression model first employed by Willis & Rosen (1979).

$$\begin{bmatrix} \varepsilon_0 \\ \varepsilon_A \\ \varepsilon_N \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho_{0A} & \rho_{0N} \\ & 1 & 0 \\ & & 1 \end{bmatrix} \right)$$

1.5.3 Exclusion Restrictions

Formally, exclusion restrictions are not required to identify the model parameters given that the MVN distributional assumption is valid. However, identification achieved based on a distributional assumption alone is considered tenuous, and the use of exclusion restrictions is beneficial (Puhani, 2000). Following, exclusion restrictions are used to estimate the off-diagonal elements of the covariance matrix (selection bias parameters) separately by exploiting sources of exogenous variation in the regime switching equation. That is, we employ exclusion restrictions to better account for selection bias in estimation of the feed adoption equations.

The sources of exogenous variation for HYV adoption are the following:

(1) Social capital exclusion restriction indicates whether or not the household head is related to, or is a neighbor of an HYV adopter in 2005, the very first year that HYV PL was made available in the market. This can be excluded from factor demand equations because the relationship with an early adopter of HYV will affect the probability of adoption, but will not affect how farm household's decision to allocate resources to production.

(2) Land tenure measures if a household owns a formal title to their aquaculture ponds. Land tenure has been found to affect long-term investment decisions (Deininger & Jin, 2006; Gebremedhin & Swinton, 2003) as the risk in insecure tenure arrangements affect the expected returns, but tenure status has been found not to affect factor input use or farming intensity (Holden & Yohannes, 2002; Place & Otsuka, 2002). In the case of shrimp farming, land tenure is important in the household’s decision to make a long-term investment to change production systems to produce the HYV, but land tenure status is not related to the short-run decision to use feed input during a production cycle.

(3) We also include the presence of mangroves, an erosion mitigating resource, as an exclusion restriction. Similar to the discussion above on land tenure, the risk of erosion will affect the household's long-term investment decisions. However, in the short run, a farm household will not consider the risk of land-loss in the decision to allocate resources for a single

production cycle. The loss of land to the ocean occurs over a long period and will not be realized within one production cycle.

(4) The output price and the PL price of the variety not being farmed by the household are excluded in the feed adoption equations. In shrimp production, input decisions are made in a sequence during the production cycle. After the varietal choice has been made, farms decide to adopt formula feed only after the shrimp have matured to a point where they can metabolize feed. Therefore, the output and PL price of the shrimp variety that is not being farmed is irrelevant to the feed adoption decision because the farm has already committed to a variety.

(5) The distance to a PL hatchery is also excluded from the feed adoption equation. The distance to a hatchery proxies the transaction cost of procuring PL. This is important for the HYV adoption decision, but is irrelevant when the household farm decides to adopt feed later on in the production cycle.

1.6 Context & Descriptive Statistics

In this section, we present descriptive statistics on the key variables of analysis. Detailed results are presented in Table 4 – 6 in the appendix. The salient results are highlighted as follows.

1.6.1 Pond area operated

The overall average pond area operated by a household is two hectares; however there is actually a large amount of heterogeneity in farm size in our sample (Table 4). A very large proportion of households are very small. Nearly a quarter of farms in our sample were “micro-farms” that operated less than half of a hectare of pond area. We also find that there are many medium size farms, with nearly 20% of the sample operated three or more hectares of ponds.

1.6.2 Capital endowment

First, we find that 45% percent shrimp farming households own water-pumps for exchanging water in aquaculture ponds (Table 6). This demonstrates that capital is not as uncommon as conventionally believed. Many household own productive capital and are capable of improving water circulation. However, this still means that more than half of farm households are without the water pumps needed to efficiently circulate water in their ponds. The lack of productive capital may be a significant barrier to intensification of shrimp farms.

Second, we find that small farms have fewer water-pumps compared to larger farms. Results show that only 28 percent of micro farms (smaller than 0.5 ha) owned a water pump while in the other size categories, over half of the households owned at least one water pump (Table 7). This difference in capital endowment may be a large factor that is keeping micro-farms from adopting the new technology.

Third, we find geographic variation in the capital endowments of the farm households. While 78 percent of farm households in Central Java own a water-pump, only 16 percent of households in South Sulawesi owned water-pumps (Table 6). This may reflect access to procuring a water pump, and perhaps also a lack of a functioning credit market in Sulawesi to finance investment.

1.6.3 HYV Adoption rate

Descriptive results show that household farms are indeed adopting the HYV technology; however we see strong geographic differences in the adoption rates. In addition, HYV adoption rates are correlated to farm size in addition to capital endowments.

First, we find that 20% of households have adopted the HYV. There is strong geographic variation in the adoption rate. While adoption of the HYV has been widespread in Central Java

(38%), it has been much slower in South Sulawesi (5%) (Table 8). This may be related to lower capital endowments, worse economic conditions, and worse infrastructure in South Sulawesi compared to Central Java.

Second, the rate of HYV adoption is much higher for larger farms than it is for smaller farms. The HYV adoption rate for micro-farms is only 14% in our sample. Larger farms (3+ hectares), on the other hand have an adoption of 28%, double the rate of micro-farms (Table 9). This suggests a farm-scale barrier in the adoption of HYV, where small farms are excluded from the adoption of HYV.

Third, the HYV adoption is related to water pump ownership. While the HYV adoption rate was only 7% for households without water pumps, it was 36% for households with at least one water pump. We see a similar relationship with feed adoption. Only 14% of those without water pumps adopted feed, but 39% with water pumps did adopt feed (Table 10). This suggests that water pumps are a complementary input to the HYV and the household's endowment of this capital item may be a critical factor in the adoption of this technology.

1.6.4 Feed adoption

In aggregate, 25% of our sample has adopted shrimp feed. However, the adoption rate for feed is different depending on the shrimp variety that the household is producing. Among HYV adopters, the adoption rate of shrimp feed is 68%, which is much higher than the feed adoption rate for conventional farmers at 16%. This shows that feed is more complementary to HYV production than it is for the traditional variety, and that the adoption of HYV is happening in conjunction with the adoption of feed. Farmers are taking advantage of the interactive effect of adopting HYV and feed together.

Second, we find that the feed adoption rate is significantly lower in South Sulawesi than it is in Central Java. The feed adoption rate in Central Java is 37% while it is only 14% in South Sulawesi. This mirrors our results on HYV adoption rates in these two provinces. We find that South Sulawesi is generally lagging behind Central Java in the adoption of both technologies.

Third, the rate of feed adoption is much higher for larger farms than it is for smaller farms. The feed adoption rate for micro-farms (<0.5 ha) is only 19% in our sample. Larger farms (3+ ha), on the other hand, have an adoption of 29%, double the rate of micro-farms. This suggests a farm-scale barrier in the adoption of feed, where small farms are excluded from the adoption of.

Fourth, the feed adoption rates are much lower for farms without productive capital. The feed adoption rate for farms without water pumps is only 14%. The adoption rate for farms with water pumps is 39%. Water pumps appear to be a complementary input to feed and the household's endowment of this capital item may be a critical factor in the adoption of this technology.

1.7 Regression Results

Salient results from estimating the model parameters using the switching probits method are presented in this section. Complete results can be found in Table 11 – 13 in the appendix.

1.7.1 Identifying conditions

To test the validity of the exclusion restrictions, and the recursive nature of the estimation, we conduct three likelihood ratio tests. First, we test if the exclusion restrictions are correlated with HYV adoption (the regime switching equation). We test if the exclusion restrictions are jointly equal to zero in the HYV adoption equations with an LR-test. The test yielded a χ^2 value of 31.22 with six degrees of freedom (p=0.00), and we reject the null hypothesis that these variables are jointly equal to zero. The exclusion restrictions satisfy the condition that they are correlated with HYV adoption.

Second, we test if the exclusion restrictions are valid in the feed adoption (regime) equations. We test if the exclusion restrictions are jointly equal to zero in the feed adoption equations (for traditional variety and HYV farms) using an LR-test. The test yielded a χ^2 value of 12.23 with 12 degrees of freedom (p=0.43), and we fail to reject the null hypothesis that these variables are jointly equal to zero. The exclusion restrictions satisfy the condition that they are not correlated with the error terms in the feed adoption equations.

Third, we test if there is evidence for endogenous switching bias in our estimation of feed adoption. We do this with an LR-test that tests if the selection bias parameters $(\rho_{12}; \rho_{13})$ are jointly equal to zero. The test yielded a χ^2 value of 6.79 with two degrees of freedom (p=0.03), and we reject the null hypothesis that these variables are jointly equal to zero. There is significant evidence for endogenous switching bias that is accounted for in estimation.

1.7.2 Farm size

First, for the adoption of HYV, we find that farm size is not a significant determinant; neither the farm-scale variable nor the intercept shift for micro-farms was found to be statistically significant. While descriptive results showed that HYV adopters tended to be larger farms, when controlling for other factors that are correlated with farm size, such as land-tenure, credit access, risk, and human capital, we see that there is no independent scale-effect on the adoption of HYV. This corroborates previous findings in the green revolution literature and adds evidence for the inclusion of small farms, an ongoing debate in the development literature (Reardon et al., 2009).

Second, for the adoption of feed, however, we find that farm size is an important factor. First, among traditional variety farmers, we find a strong threshold effect for farm-scale. Farm-scale had a significantly negative effect on the probability to adopt feed, meaning that the smallest of small farmers were the most likely to adopt feed. However after the 0.5 hectare threshold the scale-effect diminishes to nearly zero. The smallest farms may be more capable of utilizing feed more efficiently; larger farms may be more capable of supporting shrimp with naturally occurring biota while the eco-systems contained in very small ponds may require feed supplement to sustain the shrimp population.

Third, we observe the opposite relationship for HYV adopting farms. Farm-scale had a significantly positive effect on the probability to adopt feed, meaning that the smallest farmers were the least likely to adopt feed. However, after the 0.5 hectare threshold the scale-effect diminishes to zero. HYV shrimp have specific feed pellet sizes that are required at different points in the shrimp production cycle. Smaller pellet sizes are not available for purchase at the rural farm input stores, and are purchased from feed mills directly or from distributors located in rural hubs. There may be scale barriers into accessing the feed market for HYV: (1) Larger HYV farms are more able to spread the fixed cost of feed market access to larger quantity of shrimp; (2) Some distributors and feed mills require a minimum orders that the smallest farms may not be able to meet.

1.7.3 Capital holdings

For the adoption of HYV, we find that holdings of water pumps are a significant determinant of HYV adoption. Farm households that are poor in capital are significantly less likely to adopt HYV. This is because water-pumps are an important complement capital asset in the production of HYV. HYV shrimp production systems generate more waste and require improved water circulation and dredging to maintain sanitary production conditions for the shrimp.

In addition, we find that capital poor farmers producing the traditional variety are significantly less likely to adopt feed. This means that capital poor farmers are doubly constrained in farming system intensification: once with HYV adoption, and again in the adoption of shrimp feed. Capital poor farmers tend to use the least advanced shrimp production technology.

Investment into this capital item may be a significant barrier to adoption for many smallholder farmers as a single water pump can costs upwards of 300 USD, about one half of the annual returns from a single hectare of shrimp ponds.

1.7.4 Non-farm income & credit

The amount of remittance income earned by the household also had a significant positive effect on the propensity to adopt HYV. Using the estimated parameter on remittance income, the average effect of a positive shock of $10 USD in monthly remittance income, which is over double the average, would lead to a 6.6% increase in the probability that a household adopts the HYV. This suggests that (1) constrained household may not be able to make necessary investments to upgrade production systems, or purchase the more expensive HYV PL, and; (2) exogenous remittance income could be helping households cope with the risk of adopting a new aquaculture variety.

In addition to the cash constraint, the presence of a bank in the village was found to have a significant positive effect on the probability of HYV adoption. The average effect of a bank on the probability of adopting HYV is 11%. This suggests that farm households also face a credit constraint in the adoption of the HYV. Similar to the cash constrained household, credit constrained household may not be able to make the necessary investments to intensify production practices by acquiring critical capital items like water-pumps and purchasing market inputs like HYV PL.

1.7.5 Village & social capital

The presence of mangroves on the coastline of the village was found to significantly increase the probability of adoption. Mangroves serve as (1) a long-run risk-mitigating factor that is important in protecting the aquaculture ponds and any infrastructure investments made into the ponds from eroding away into the ocean; (2) as a sediment sink and waste filter that cleanses the higher levels of effluent produced via HYV production. Results show that the eco-system services provided by mangrove resources are an important factor driving HYV adoption, and that those without mangrove resources are more likely to remain trapped farming the traditional variety.

Being a neighbor of an early adopter has a significant positive effect on the probability to adopt HYV. This means that knowledge gained from neighbors regarding production practices, and markets for inputs and outputs built capacity in the farm household to intensify production by adopting HYV.

Membership in an aquaculture producer organization was also found to have a positive significant effect on the propensity to adopt HYV. The information diffused in the group, the ability to collectively manage shared resources, and also the ability to act as a buying or selling collective to access markets is an important factor in determining the farm household's probability of HYV adoption.

1.7.6 Distance to hatchery

Distance to hatchery was found to have a significant negative effect on the probability to adopt. This means that shrimp aquaculture intensification is occurring in spatial clusters surrounding agricultural business. Spatial cluster may help to reduce overall transaction costs of procuring inputs, marketing outputs, and diffusing information regarding new technologies.

1.7.7 Robustness checks

We check for the robustness of our estimated parameters by estimating two additional regression specifications. First, we estimate each adoption equation separately using a conventional probit estimator. Second, we estimate each adoption equation separately using a conditional-random-effect probit estimator that accounts for some of the time invariant household unobserved factors.

Results from the robustness checks are presented alongside our primary regression results. While CRE probits tended to inflate the estimated parameters, the sign and significance of the results were robust across all of the different regression specifications.

1.8 Summary & Conclusions

Responding to declining productivity of fisheries, the world is turning increasingly to aquaculture to expand production and meet the increasing global demand for seafood. This study examines the adoption of (1) shrimp HYV and (2) subsequent adoption of formulated shrimp feeds, two shrimp aquaculture technologies that are critical to increasing productivity of shrimp farming in Indonesia. The primary objective was to identify if land-poor or capital-poor farm households were excluded in adopting HYV and/or the adoption of feed. The study used primary data collected in Indonesia to estimate the HYV and feed adoption equations. The results show that:

(1) We do not find evidence for smallholder exclusion in the adoption of HYV. There are many HYV adopters among small farmers.

(2) One of these constraints is the endowment of productive capital. We found that households that are poor in capital were significantly less likely to adopt HYV and shrimp feed. Farmers with low capital endowments are doubly constrained in the adoption of HYV and of shrimp feed. This may constitute a sort of “low-productivity trap” in aquaculture – with the asset-poor relegated to producing the unproductive traditional variety without external inputs.

(3) There are contrasting farm-scale effects on feed adoption for HYV and traditional farm households. While the smallest HYV producing farms were the least likely to adopt feed, the smallest traditional variety producing farms were the most likely to adopt feed. There is evidence for smallholder exclusion in the adoption of a fully intensive shrimp aquaculture technology.

(4) In the adoption of feed, there is a strong threshold effect at half of a hectare. This demonstrates that all of the important variation in farm size is occurring below the half-hectare threshold and the marginal effect of farm-scale after this threshold is nearly zero. Micro-farms are a unique subset of the farming population that are oftentimes the most productive in using traditional technologies, but are constrained in fully intensive adoption of novel production systems.

APPENDIX

APPENDIX

Figure 1: Aggregate output in Indonesia (MT)

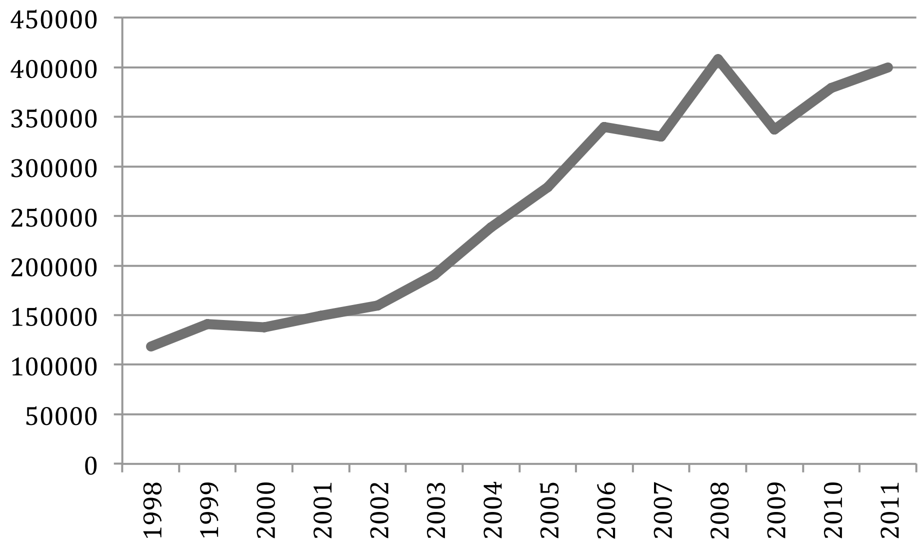

Figure 2: Aggregate output in Indonesia by variety (MT)

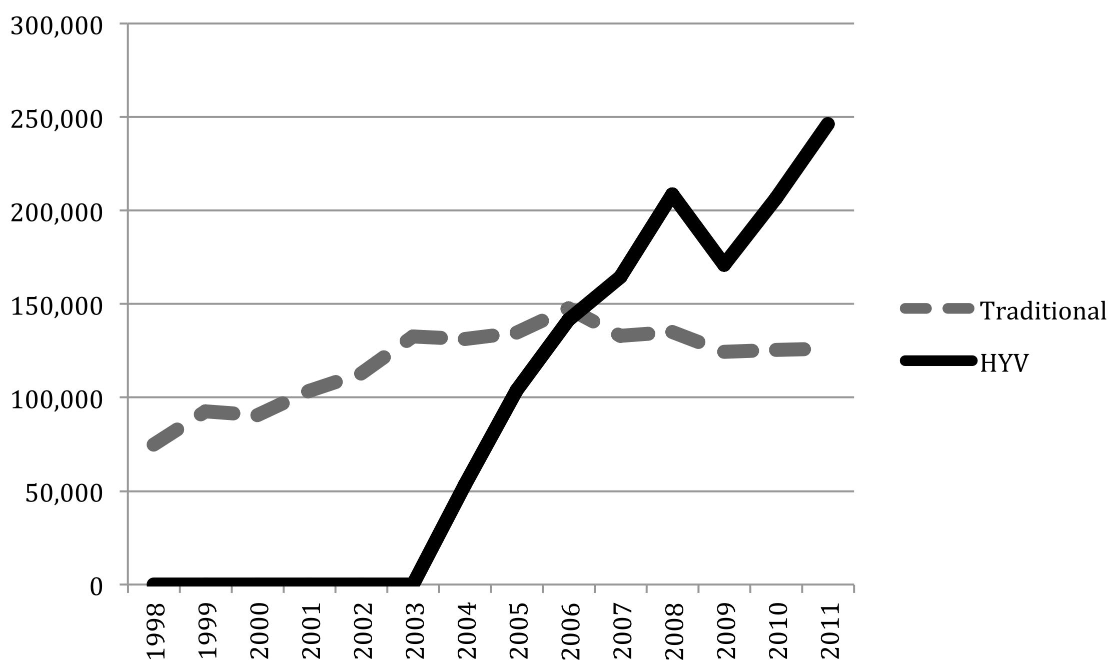

Figure 3: Stylized farm technology

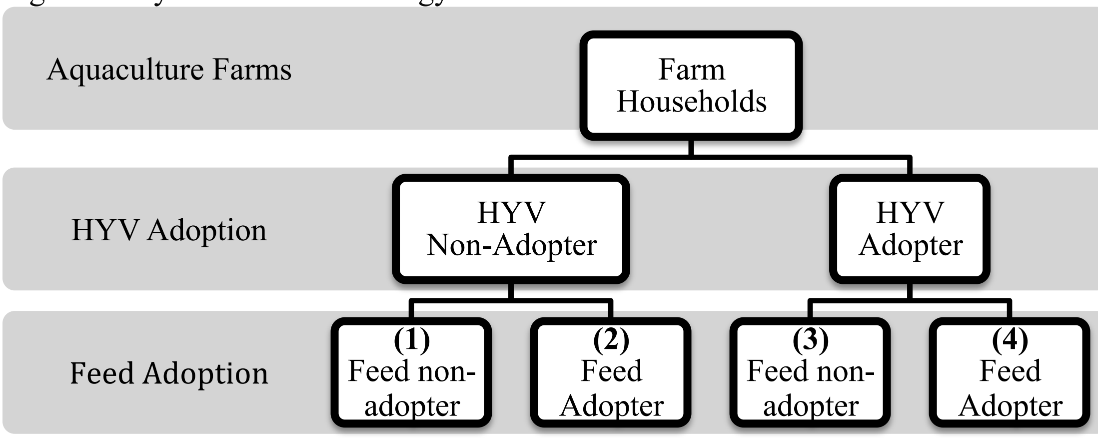

Table 1: Census of shrimp farming households

	South Sulawesi		Central Java		Overall
	Barru	Bulukumba	Rembang	Brebes	
HYVAdopters	46	10	118	271	445
Non-Adopters	861	286	230	437	1814
TOTAL	907	296	348	708	2259
Adoption Rate	5%	3%	34%	38%	20%

Table 2: Sample totals by district

	South Sulawesi		Central Java		Overall
	Advanced	Low	Advanced	Low	Advanced
HYV Adopters	27	7	84	102	220
Non-Adopters	305	161	165	149	780
Overall	332	168	249	251	1000

Table 3: Response Rates

VARIABLES	Response Rate
Aquaculture pond area operated - lagged (ha)	99.5%
Household operates a 'Micro-Farm' <0.5 ha (binary 0/1)	99.5%
Crop land area operated - lagged (ha)	99.5%
Depth of pond (dm)	99.5%
# of water pumps owned - lagged (count)	98.8%
# of adults in HH (over 16 yrs.)	99.5%
Household Head Age	99.5%
Experience of HH head in 2010	99.5%
Education of HH head (years)	98.8%
Non-farm income (Million IDR)	99.2%
HH head is a member of an aquaculture producer organization (binary 0/1)	99.5%
Village has a bank branch (binary 0/1)	99.5%
Village has a government extension office (binary 0/1)	99.1%
Risk (Probability of below subsistence yield)	99.5%
Village price of size 30 Traditional output -lagged (USD/Kg)	99.5%
Village price of size 60 HYV output -lagged (USD/Kg)	99.5%
Village price of 15 day old Traditional post-larval shrimp (USD/1000 PL)	99.5%
Village price of 12 day old HYV post-larval shrimp (USD/1000 PL)	99.5%
Village price of shrimp feed (USD/50Kg)	99.5%
Distance to Hatchery (min. of travel)	99.5%
Village has erosion mitigating mangrove barriers (binary 0/1)	99.5%
HH owns formal title to pond (binary 0/1)	99.5%
HH head is a related/friend of an early adopter (2005)	98.5%
	N=1000

Table 4: Household land assets by farm size

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Overall	<0.5	0.5-1 ha	1-2 ha	2-3 ha	3+ ha
Aquaculture pond area operated (ha)	2.02	0.32	0.86	1.59	2.62	5.80
	(0.078)	(0.011)	(0.011)	(0.021)	(0.035)	(0.236)
Crop land area operated (ha)	0.44	0.35	0.43	0.43	0.44	0.56
	(0.032)	(0.055)	(0.063)	(0.061)	(0.095)	(0.092)
Household operated crop-land (binary)	0.39	0.44	0.38	0.39	0.37	0.38
	(0.016)	(0.035)	(0.033)	(0.034)	(0.048)	(0.037)
Observations	988	223	239	225	110	191

Table 5: Land assets by HYV adoption

VARIABLES	(1) Overall	(2) Non-Adopter	(3) Adopter
Aquaculture pond area operated (ha)	2.02	1.88	2.57
	(0.078)	(0.081)	(0.209)
Crop land area operated (ha)	0.44	0.43	0.45
	(0.032)	(0.033)	(0.086)
Household operated crop-land (binary)	0.39	0.41	0.33
	(0.016)	(0.018)	(0.034)
Observations	988	768	220

Table 6: Productive capital by geography

VARIABLES	(1) Overall	(2) Central Java	(3) South Sulawesi
Household owns a waterpump (binary)	0.45	0.78	0.16
	(0.016)	(0.020)	(0.017)
Waterpumps owned by the household (count)	0.69	1.23	0.21
	(0.034)	(0.057)	(0.025)
Observations	988	493	495

Table 7: Productive capital by farm size

VARIABLES	(1) Overall	(2) <0.5	(3) 0.5-1 ha	(4) 1-2 ha	(5) 2-3 ha	(6) 3+ ha
Household owns a waterpump (binary)	0.45	0.28	0.45	0.52	0.55	0.52
	(0.016)	(0.030)	(0.033)	(0.035)	(0.050)	(0.038)
Waterpumps owned by the household (count)	0.69	0.32	0.53	0.71	0.90	1.18
	(0.034)	(0.036)	(0.046)	(0.056)	(0.112)	(0.125)
Observations	988	223	239	225	110	191

Table 8: Adoption by geography

VARIABLES	(1) Overall	(2) Central Java	(3) South Sulawesi
HH has adopted HYV (binary)	0.20	0.38	0.05
	(0.013)	(0.023)	(0.008)
HH has adopted feed (binary)	0.25	0.37	0.14
	(0.014)	(0.023)	(0.016)
Observations	986	490	496

Table 9: Adoption by farm size

VARIABLES	(1) Overall	(2) <0.5	(3) 0.5-1 ha	(4) 1-2 ha	(5) 2-3 ha	(6) 3+ ha
HH has adopted HYV (binary)	0.20	0.14	0.16	0.24	0.21	0.28
	(0.013)	(0.021)	(0.024)	(0.030)	(0.042)	(0.035)
HH has adopted feed (binary)	0.25	0.19	0.25	0.28	0.24	0.29
	(0.014)	(0.025)	(0.029)	(0.031)	(0.044)	(0.034)
Observations	986	223	237	224	108	194

Table 10: Adoption by capital holding

VARIABLES	(1) Overall	(2) No pump	(3) Owns pump
HH has adopted HYV (binary)	0.20	0.07	0.36
	(0.013)	(0.011)	(0.024)
HH has adopted feed (binary)	0.25	0.14	0.39
	(0.014)	(0.015)	(0.024)
Observations	986	522	464

Table 11: HYV Adoption Regression Results

VARIABLES	(1) Probit	(2) CRE	(3) FIML System
Aquaculture pond area operated - lagged (ha)	0.20	0.14	-0.12
	(0.291)	(0.855)	(0.283)
Pond area * Dummy for farms >0.5 ha (ha)	-0.19	-0.10	0.13
	(0.287)	(0.844)	(0.278)
Crop land area operated - lagged (ha)	0.01	0.03	0.00
	(0.032)	(0.097)	(0.033)
Depth of pond (dm)	-0.00	-0.00	0.00
	(0.010)	(0.030)	(0.010)
# of water pumps owned - lagged (count)	0.20**	0.46**	0.22**
	(0.039)	(0.124)	(0.046)
# of adults in HH (over 16 yrs.)	0.01	0.01	-0.00
	(0.035)	(0.105)	(0.033)
Household Head Age	-0.00	-0.00	-0.00
	(0.003)	(0.009)	(0.003)
Experience of HH head in 2010	-0.00	-0.00	-0.00
	(0.007)	(0.021)	(0.008)
Education of HH head (years)	0.01	0.02	0.01
	(0.009)	(0.028)	(0.009)
Non-farm income (Million IDR)	0.34*	0.73	0.34**
	(0.139)	(0.389)	(0.118)
HH head is a member of an aquaculture producer	0.26**	0.73**	0.28**
organization (binary 0/1)	(0.085)	(0.243)	(0.088)
Village has a bank branch (binary 0/1)	0.54**	1.31**	0.55**
	(0.106)	(0.338)	(0.111)
Village has a government extension office (binary 0/1)	0.13	0.23	0.05
	(0.125)	(0.364)	(0.120)
Village yield risk (Std. dev. of yield/ha)	0.14**	0.37**	0.15**
	(0.021)	(0.071)	(0.027)
Village price of size 30 Traditional output -lagged	-0.43**	-0.95**	-0.37*
(USD/Kg)	(0.120)	(0.350)	(0.156)
Village price of size 60 HYV output -lagged	-0.02	0.15	-0.04
(USD/Kg)	(0.203)	(0.552)	(0.232)
Village price of 15 day old Traditional post-larval	0.69**	1.27*	0.55*
shrimp (USD/1000 PL)	(0.241)	(0.568)	(0.240)
Village price of 12 day old HYV post-larval	-0.28	-0.42	-0.22
shrimp (USD/1000 PL)	(0.204)	(0.480)	(0.196)
Village price of shrimp feed (USD/50Kg)	0.05	0.06	0.05
	(0.026)	(0.063)	(0.025)
Distance to Hatchery (min. of travel)	-0.02**	-0.05*	-0.02**
	(0.007)	(0.023)	(0.006)
Village has erosion mitigating mangrove barriers	0.31**	0.73*	0.28*
(binary 0/1)	(0.105)	(0.311)	(0.119)

Table 11 (cont'd)

VARIABLES	(1) Probit	(2) CRE	(3) FIML System
HH owns formal title to pond (binary 0/1)	-0.01	0.06	-0.03
	(0.089)	(0.265)	(0.093)
HH head is a related/friend of an early adopter (2005)	0.36**	0.87**	0.31**
	(0.086)	(0.267)	(0.087)
Brebes District (binary 0/1)	0.11	0.41	0.21
	(0.127)	(0.380)	(0.141)
Bulukumba District (binary 0/1)	-0.66**	-1.47*	-0.63**
	(0.197)	(0.579)	(0.222)
Barru District (binary 0/1)	-0.46*	-0.79	-0.61*
	(0.222)	(0.579)	(0.280)
Constant	-1.28**	-3.07**	-1.13**
	(0.349)	(1.068)	(0.368)

** p<0.01, * p<0.05

Table 12: Traditional variety farmer feed adoption

LABELS	(1) Probit	(2) CRE	(3) FIML System
Aquaculture pond area operated - lagged (ha)	-0.57	-1.36	-0.68*
	(0.309)	(1.691)	(0.297)
Pond area * Dummy for farms >0.5 ha (ha)	0.57	1.46	0.69*
	(0.304)	(1.670)	(0.293)
Crop land area operated - lagged (ha)	-0.13*	-0.55	-0.09*
	(0.056)	(0.324)	(0.046)
Depth of pond (dm)	0.04**	0.13**	0.04**
	(0.010)	(0.049)	(0.009)
# of water pumps owned - lagged (count)	0.21**	1.18**	0.26**
	(0.049)	(0.271)	(0.046)
# of adults in HH (over 16 yrs.)	0.03	0.12	0.02
	(0.033)	(0.193)	(0.032)
Household Head Age	-0.00	-0.02	-0.00
	(0.003)	(0.017)	(0.003)
Experience of HH head in 2010	0.01	0.03	0.00
	(0.007)	(0.039)	(0.007)
Education of HH head (years)	0.02*	0.06	0.02*
	(0.009)	(0.056)	(0.009)
Non-farm income (Million IDR)	0.14	0.30	-0.01
	(0.201)	(1.383)	(0.223)
HH head is a member of an aquaculture producer	0.14	0.52	0.19*
organization (binary 0/1)	(0.085)	(0.474)	(0.082)
Village has a bank branch (binary 0/1)	-0.02	-0.32	0.11
	(0.106)	(0.609)	(0.108)
Village has a government extension office	0.21	0.76	0.31**
(binary 0/1)	(0.123)	(0.749)	(0.110)
Village yield risk (Std. dev. of yield/ha)	0.08**	0.13	0.17**
	(0.029)	(0.151)	(0.032)
Village shrimp output price (USD/Kg)	-0.05	0.77	-0.22
	(0.126)	(0.503)	(0.126)
Village PL price (USD/PL)	0.18	-0.64	0.48
	(0.269)	(1.233)	(0.284)
Village price of shrimp feed (USD/50Kg)	-0.01	-0.06	-0.01
	(0.018)	(0.087)	(0.016)
Brebes District (binary 0/1)	0.49**	1.31	0.56**
	(0.150)	(0.797)	(0.149)
Bulukumba District (binary 0/1)	0.02	0.45	-0.05
	(0.160)	(0.856)	(0.169)
Barru District (binary 0/1)	0.15	0.30	0.08
	(0.187)	(0.953)	(0.210)
Constant	-1.99**	-11.79**	-1.99**
	(0.267)	(1.376)	(0.292)

** p<0.01, * p<0.05

Table 13: HYV farmer feed adoption

LABELS	(1) Probit HYV Feed	(2) CRE HYV FEED	(3) FIML HYV Feed
Aquaculture pond area operated - lagged (ha)	2.48**	7.97*	1.74*
	(0.720)	(3.210)	(0.715)
Pond area * Dummy for farms >0.5 ha (ha)	-2.46**	-7.87*	-1.72*
	(0.715)	(3.184)	(0.711)
Crop land area operated - lagged (ha)	-0.02	-0.11	-0.03
	(0.042)	(0.174)	(0.041)
Depth of pond (dm)	0.02	0.17	0.04*
	(0.020)	(0.100)	(0.019)
# of water pumps owned - lagged (count)	0.10	0.48	0.03
	(0.068)	(0.318)	(0.081)
# of adults in HH (over 16 yrs.)	0.01	0.11	0.01
	(0.070)	(0.338)	(0.069)
Household Head Age	0.00	0.02	0.00
	(0.006)	(0.028)	(0.006)
Experience of HH head in 2010	-0.06**	-0.36**	-0.05**
	(0.022)	(0.093)	(0.017)
Education of HH head (years)	0.02	0.17	0.01
	(0.018)	(0.098)	(0.018)
Non-farm income (Million IDR)	0.07	0.05	-0.02
	(0.166)	(0.575)	(0.113)
HH head is a member of an aquaculture producer	0.02	0.04	0.10
organization (binary 0/1)	(0.158)	(0.798)	(0.158)
Village has a bank branch (binary 0/1)	-0.39	-2.24	-0.50*
	(0.200)	(1.282)	(0.202)
Village has a government extension	0.84**	5.64**	0.87**
office (binary 0/1)	(0.229)	(1.271)	(0.251)
Village yield risk (Std. dev. of yield/ha)	0.02	0.11	0.00
	(0.013)	(0.061)	(0.012)
Village shrimp output price (USD/Kg)	-0.20	-1.82	-0.21
	(0.318)	(1.241)	(0.323)
Village PL price (USD/PL)	0.55	2.84	0.33
	(0.515)	(2.107)	(0.498)
Village price of shrimp feed (USD/50Kg)	-0.01	-0.12	0.00
	(0.056)	(0.236)	(0.058)
Brebes District (binary 0/1)	-0.60**	-3.82**	-0.57**
	(0.197)	(1.145)	(0.205)
Bulukumba District (binary 0/1)	-0.54	-3.24	0.04
	(0.447)	(2.396)	(0.529)
Barru District (binary 0/1)	0.02	1.79	0.42
	(0.352)	(1.620)	(0.429)
Constant	-0.23	-1.06	0.28
	(0.441)	(2.129)	(0.682)

** $p<0.01$, * $p<0.05$

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Chapter 2: The diffusion of shrimp HYV and mangrove forest rehabilitation

2.1 Introduction

Mangroves are an important natural resource found on tropical coastlines, and they serve as an important protective barrier against the threat of erosion and subsidence into the ocean (Barbier, 2007; Rönnbäck, 1999). However, urbanization and expansion of farms have put pressure on mangrove forests (Barbier & Cox, 2004; Ron & Padilla, 1999; Valiela et al., 2001). This has resulted in the destruction of 86% of the world's mangrove resources in the last quarter century, leaving many coastal communities in a "world without mangroves" (Duke et al., 2007), and exposed to the threat of coastal erosion.

In light of the poor state of mangrove forests, attention is shifting away from passive conservation efforts towards active replanting programs to rehabilitate lost forests. Governments have been keen on rehabilitating mangrove forests to protect valuable land in coastal communities, however centrally planned mangrove planting programs have faced many challenges and were met with limited success (Walters et al., 2008). As a result, attention is now focusing more on how to initiate and support community-based efforts to plant mangroves on vulnerable coastlines.

This study examines the rise of community-based mangrove planting initiatives in Indonesia, a country of over 17,000 islands with 54,000km of coastline (CIA, 2013) that has vested interest in preventing coastal erosion. Recently, Indonesian villages have been observed replanting coastal mangrove forests on coastlines (Babo & Froehlich, 1998), however, the factors that are driving these villages to rehabilitate mangroves have not yet been identified. The main objective of this study is to identify the factors that are motivating coastal villages in Indonesia to replant mangroves forests, and what factors may be preventing other villages from doing the same.

In essence, the planting of mangrove forests is a type of investment into soil conservation. It is similar in concept to the use of bunds, terraces, and conservation tillage practices, the adoption of which has been studied at the household level (Knowler & Bradshaw, 2007). Unlike the common soil conservation measures studied in the literature, mangrove forests are more of a common-pool resource in that: (1) they provide benefits to all members of the coastal community in the form of erosion and subsidence mitigation; (2) it is difficult to exclude specific community members from mangrove benefits, and; (3) the magnitude of benefits that the community accrues depends on the participation of individual community members in replanting mangroves in the community. This study adds to the literature on soil-conservation by modeling the replanting of mangroves, a common-pool soil resource, at the village community level.

We focus our analysis on the effect of two important factors on the rehabilitation of mangrove forests:

FIRST is the level of technology diffusion in the community. Mangroves are very important for shrimp farmers. Currently, shrimp farming systems are intensifying with the diffusion of a shrimp HYV (*Litopenaeus vannamei*) that significantly increases farm productivity (Briggs et al., 2004). The intensification of farming systems may be changing how shrimp farming communities utilize and depend on mangrove resources. In addition, the diffusion of HYV shrimp technology also represents heterogeneity in the village populations which is important in determining natural resource outcomes (Agrawal, 2003). The effect of shrimp HYV diffusion on mangrove forests remains unknown, and the main research question of this study is:

Research question 1: *Does the diffusion of HYV increase or decrease the propensity that a village rehabilitates mangrove forests?*

Past studies identifying the impact of technology diffusion on forest resources have put forth two competing hypotheses: on one side, the famous Borlaug (2007) hypothesis posits that technology adoption reduces deforestation because the gains to farm productivity relieve the pressure for farms to expand onto forested lands. On the other side, studies have pointed out that intensive farming practices increase the net returns to land, which actually increase incentives for farms to expand onto forested land (Angelsen & Kaimowitz, 2001; Kaimowitz & Angelsen, 1998). We add to previous studies by testing the effect of technology diffusion on *reforestation* to identify if a new technology can drive communities to rehabilitate a degraded resource.

SECOND is variation in local institutions and governance mechanisms. The literature has found that the ability of local institutions to devise policy, monitor behavior, and enforce compliance are important in determining natural resource outcomes in the community (Baland & Platteau, 1996; Ostrom, 1990; Wade, 1989). In Indonesia, there are multiple institutions in coastal communities that may be playing a part in facilitating mangrove-planting initiatives. Villages can have: (1) shrimp producer organizations; (2) village labor pooling cooperatives, and; (3) utilize different enforcement mechanisms to ensure compliance to directives. How these different institutions are affecting natural resource outcomes remains unknown, and leads to our second research question:

Research question 2: *What effect do village institutions have on the mangrove replanting behavior of the community?*

We test the relative effect of the different village institutions on the propensity that the village allocates labor to plant mangroves on the coastline

Methodologically, research on community level management of natural resources has primarily been conducted using case-studies and low-N statistics that often suffer from omitted variables (Agrawal, 2003). We add to this literature by using data from a survey of 75 coastal villages in Indonesia to conduct quantitative analysis controlling for all relevant factors.

2.2 Theoretical Model

We model the village mangrove investment decision as a two-stage process that is solved through backward induction. In the first stage, the village decides whether or not to implement a mangrove-planting program. In the second stage, individual village members decide to allocate labor to mangrove planting when the village executes the mangrove-planting program.

In the rest of this section we discuss how the villages decision rule to implement a program, how the village forms it's belief on how much labor will be provided if a program is to be implemented, and the final Nash equilibrium solution that models the whether or not a village implements a mangrove planting program.

2.2.1 Simple village decision rule

The village will initiate and plan a mangrove-planting program if the village anticipates that there will be enough participation in the program by members of the village. To model this decision, we begin with a simple decision rule for the village where villages choose to organize a collective mangrove-planting program ($Y = 1$), if the village believes it will be able to produce enough mangroves to sustain growth of the forest.

$$Y = \begin{cases} 1, & if\ g(M, L) > \mu \\ 0, & otherwise \end{cases}$$

g(•) is the growth function of mangroves. It depends on (1) M, any pre-existing mangrove, and; (2) L, the amount of labor allocated to mangrove planting.

Mangrove forest stocks have a critical mass. The critical mass (μ) is the minimum stock of mangroves necessary to maintain a steady state of mangroves. Below this point, the forest cannot sustain itself and the forest stock will decline over time. Above this point, the forest sustains itself and grows over time. If the amount of labor to be allocated to mangroves planting, L, is not sufficient to reach the critical mass (μ), the village will not initiate a planting program.

When deciding to initiate a mangrove-planting program, the village cannot observe L, the amount of labor that will be allocated at the future time of program execution. To form its belief on future labor (L^*) the village obtains credible commitments from each village member (ℓ_i^*) on how much labor they would be willing to contribute.

A credible commitment is established when the village can observe that (1) it is in the self-interest of the individual village member to contribute labor, and; (2) that there are institutions in place to prevent free riding at the time of the program's execution. Then, each of these individual credible commitments are added up to form the village's belief on how much labor will be allocated by village members at the time of the program.

If the village does not initiate a mangrove planting program, each individual will allocate zero labor to mangrove planting because no single member can allocate enough labor to surpass the threshold μ. The village's belief on total labor allocation is as follows:

$$L^* = \begin{cases} \sum_{i}^{n} \ell_i^* , & if\ Y = 1 \\ 0 , & if\ Y = 0 \end{cases}$$

2.2.2 Household's optimization problem:

To obtain a credible commitment with each village member, the village must first see that it is in the self-interest of the household to allocate labor to mangrove planting. To observe this, the village solves the household's optimization problem.

We begin with the model of an individual household maximizing a discounted expected utility stream. Households maximize utility by allocating labor to mangroves, choosing the production technology, and choosing the level of consumption and savings. The household's utility function, $u(\bullet)$, depends on consumption, c, and the utility in future periods is discounted at constant rate, β.

The household objective is expressed as follows:

$$\underset{v_t\ \ell_t\ c_t\ s_t\ x_t}{Max}\ E\left[\sum_{t=0}^{\infty}\beta^t u(c_t)\right]$$

Where *t* subscripts the time period. v represents the variety of shrimp farmed. ℓ represents the household's labor allocation. S is the cash savings (or debt) of the household. x>0 represents a good (shrimp) produced, and x<0 represents factor inputs used such as PL, and feed. The household is subject to the following constraints:

(i) $\sum_i (p_i + t_i)(x_{it} - c_{it}) - S_t = 0$, budget constraint

(ii) $t = h(K)$, transaction costs

(iii) $\beta S_{t+1} = S_t$, interest on savings (or borrowing)

(iv) $S_i \geq S_{min}$, credit constraint

(v) $f\left(x_t, \ell_t^f, T_t, v_t\right) = 0$, production technology

(vi) $T_{t+1} = \varphi(\mathrm{T_t},\ \mathrm{M_t}),$ land retained into next period

(vii) $M_{t+1} = g(M_t\ ,\ \ell_t^m + L_v^*)$, mangrove stock update

(viii) $\bar{L} = \ell_t^m + \ell_t^f$, labor constraint

S_{min} is the household's credit limit. p_i is the market price that the household faces. t represents the transaction costs. K is the vector of institutional capital in the village. T is pond area operated by the household. ℓ_t^m represents labor allocated to mangrove planting, ℓ_t^f represents the labor allocated to farm production, and L_v^* represents the household's belief on how much labor the rest of the village will allocate to mangrove planting.

2.2.2.1 Updating land endowment with erosion loss

The household's endowment of land is at risk of erosion and subsidence. The size of the household's land endowment is determined by constraint (vi), where φ(•) represents the amount of land that the household expects to retain in the next period. The amount of land that is retained is a function of the village's mangrove stock, $\mathrm{M_{t+1}}$ and the amount of land at risk $\mathrm{T_t}$. Having mangroves line the coast increases the amount of land that is retained, so households have incentive to improve mangrove stocks.

2.2.2.2 Updating village mangrove stock

The village's mangrove stock updates in the manner specified in constraint (vii). Recall that g(•) is a function of the household's labor allocation ℓ^m plus the total labor allocation of the remaining village members L_v^*. Households will incorporate their beliefs on how much labor others will allocate in their own decision to allocate labor.

In addition, g(•) is not a linear function with respect to labor. At low levels of labor, the marginal productivity of labor is also low. Mangrove planting is most productive when a large labor pool is assembled to: (i) collect seeds and saplings from nearby forests; (ii) plant saplings along the village's coastline all at once, and; (iii) monitor and manage mangrove growth in the early stages of development. This means that the benefit of allocating labor to planting mangroves will outweigh the opportunity cost only if many other members of the village will also be allocating labor to plant mangroves.

2.2.2.3 Shrimp varietal choice

The household will choose the optimal shrimp variety to produce given its relative tradeoffs. The traditional shrimp HYV is a land-intensive labor-saving technology, while HYV is a land-saving labor intensive technology. While the yield of the HYV is higher, HYV production also makes more use of farm-assets, and requires transactions in unfamiliar input and output markets.

2.2.3 Solutions to the household problem

Following, the household's constrained optimization problem can be decomposed into a two period problem in which the household maximizes utility by allocating labor, choosing production technology, in addition to consumption and savings levels. The dynamic programming problem is expressed with the following value function that is subject to constraints (i) through (viii)

$$V(M_t, T_t, K_t, Y_t) = \underset{v_t\ \ell_t\ c_t\ s_t\ x_t}{MAX}\ u(C_t) + \beta V(M_{t+1}, T_{t+1}, K_{t+1}, Y_t)$$

2.2.3.1 Shrimp varietal choice

With manipulation of first order conditions, we can derive the equations for household *i*'s varietal choice. The following equation represents the varietal choice in the current period:

$$v^*(p_t, M_t, K_t, T_t)$$

The diffusion of shrimp HYV in the village is the sum of the individual adoption decisions of each household:

$$D_t^* = \sum_i^{Nv} v_{it}^* = v(p_t, M_t, K_t, T_t)$$

2.2.3.2 Mangrove labor allocation

With manipulation of first order conditions, we can derive the equations for household *i*'s allocation of labor to plant mangroves as follows:

$$\ell_{it}^m = \begin{cases} m(p_t, T_{it}, M_t, K_t, v_t, L_v^*) , & if\ Y = 1 \\ 0 , & if\ Y = 0 \end{cases}$$

where $L_v^* = \sum \ell_j^m$, the rest of the village's contribution of labor to planting mangroves.

Household *i* will allocate zero labor to mangrove planting if there is no village program, and will allocate labor according to function m(•) when there is a program.

By symmetry, household j's supply of labor is expressed as follows:

$$\ell_{jt}^m = \begin{cases} m\left(p_t, T_{jt}, M_t, K_t, V_t, \sum \ell_i^{m*}\right) , & if\ Y = 1 \\ 0 , & if\ Y = 0 \end{cases}$$

Note that household i's allocation of labor to plant mangroves also depends on household j's allocation, and vice versa.

To solve for household i's optimal labor allocation, we can theoretically substitute in the optimal labor functions for all other households in the village into household i's expression and solve for household i. This is the Nash equilibrium labor allocation of household *i* that takes into consideration the reaction functions of all other members of the village. We express this final allocation decision as the following equation:

$$\ell_{it}^{m*} = m(p_t, M_t, K_t, D_t, T_t, Y_t)$$

2.2.3.3 Village institutions

Recall that village institutions, K, play an important role in determining the transaction costs that an individual household faces in the market. Producer organizations, labor cooperatives, and enforcement mechanisms used in the village help to reduce the transaction costs associates with making trades.

If village members deviate from their labor commitment, they face the risk of expulsion, or restricted benefits from these institutions. The reputation and social capital invested in these institutions help to ensure that individuals will follow through on the commitments they make to the community. Households will have incentive not to free-ride when there are institutions in place that are enforcing compliance.

2.2.4 Village's solution

The village sums up the individual commitments to form the aggregate belief on village labor allocated to mangrove planting L^*. The village makes the decision using this decision rule:

$$Y = \begin{cases} 1, & if\ g(M, L^*) > \mu \\ 0, & otherwise \end{cases}$$

Then it follows that the reduced form equation to model how a village will decide to initiate a program is expressed as follows:

$$Y_t^* \ (p_t, M_t, K_t, D_t, T_t)$$

2.3 Data

To answer our research questions, we analyze data from a survey of 75 coastal villages in Indonesia conducted in July and August of 2010. This section discusses (1) the design of the survey instrument and; (2) the survey sample.

2.3.1.1 Questionnaire Development

The development of the questionnaire took place between April and July of 2010. Pre-testing of the questionnaire was conducted as an iterative process where a questionnaire draft is tested and then revised with information obtained from the testing-round. During this stage, multiple questionnaire drafts were taken to the field and tested on village heads in order (1) to correct confusing wording and simplify any concepts that were not readily understood by a respondent. This means using local vocabulary and sometimes restructuring of questions so that village heads could answer accurately and promptly; (2) to reduce the complexity of the questionnaire structure for ease of use by enumerators and reduce error in enumeration; (3) to make the questionnaire flow and transition in order to make the interview process easier to conduct; (4) edit and revise questionnaire in response to any new information acquired from pre-test respondents.

The survey collected detailed information on: (1) prices of inputs and outputs; (3) village populations and characteristics; (3) institutions that govern the village; (4) village mangrove stock and planting behavior.

2.3.1.2 Survey Sample

We purposely sample from the population of coastal villages with shrimp aquaculture farming as a source of farm income to identify directly the tradeoff between shrimp aquaculture production and investment into mangrove planting. In this section we discuss the design of the survey in how we: (1) chose the provinces of study; (2) chose the districts within these provinces, and; (3) census the population of coastal villages within each district.

2.3.2 Provinces selection

To select the provinces in which to administer our survey of coastal villages, we set out to choose two provinces that represent the two major types of provinces in Indonesia: (1) Developed and; (2) Hinter-island. The provinces chosen are Central Java and South Sulawesi. The selection of these two different provinces as our study sites allows us to capture a range of different incentives, capacities, and resultant behaviors of coastal communities in Indonesia.

2.3.2.1 Central Java (CJ)

We chose Central Java to represent the "developed" provinces in Indonesia that are typical to the island of Java, the most populated island of Indonesia. Central Java is a province located in the center of the island of Java, and is one of the major aquaculture production regions in Indonesia. The aquaculture producing villages in Central Java are located along the northern coast and are nearby the well-maintained major interstate highway that connects Jakarta, the primary port of Indonesia, with Surabaya, the second largest port.

2.3.2.2 South Sulawesi (SS)

We chose South Sulawesi to represent the "hinter-island" provinces of Indonesia that are found off of the main island of Java and are less densely populated compared to Java. South Sulawesi province is located on the southwestern part of the island of Sulawesi (Celebes). The main production areas of South Sulawesi are located along the western cost of the province, and are typically near the Trans-Sulawesi highway that connects cities to the major port of Makassar, and also in the southern coast which has poor road infrastructure. Rural economies in South Sulawesi are generally less developed compared to those found on the island of Java. Inclusion of South Sulawesi in the study allows us to model the behavior of villages in "hinter-island" settings.

2.3.3 District Selection

Within each selected province, we chose two districts that represent two different types of shrimp production zones: (1) Districts that are close to a major city or port; (2) Districts that are far from a major city or port. One of each type of district was selected from each province giving a total of 4 districts in our sample.

2.3.4 Village Level Census

In each of the selected districts, we conducted a census of all coastal aquaculture villages. Enumerators collected data by interviewing the head of each village and gathering population data from the village level administrative offices. Enumeration began in the eastern most villages in each district and worked westward along the coasts of each district until the administrative border of the next district was reached. The use of formal appointments with village offices allowed us to achieve a 100% response rate for the survey of villages.

Because provinces and districts were not randomly chosen, the generalization of results should remain within the geographic boundaries of the four districts in our sample.

2.4 Model Specification and hypotheses

Recall that the village's mangrove-labor allocation L is a function of prices (p), village mangrove stock (M), village institutional capital (K), the diffusion of shrimp technology (D), and the endowment of land (T). In this section we describe how each of these variables are measured, and the hypotheses associated with the included variables.

2.4.1 Dependent variable: village planted mangroves (Y_t)

Y_t indicates if the village initiated a program to replant mangroves in 2009 to 2010. Y_t is observed as a binary dependent variable taking on the value of one if the village has conducted a mangrove replanting program and zero other wise.

$$Y_t = \begin{cases} 1, & mangrove\ planted \\ 0, & otherwise \end{cases}$$

2.4.2 Explanatory variables

2.4.2.1 Prices (p)

To control for the variation across villages in the returns to farming and wage labor, we include: (1) the output prices of one kilogram of HYV and traditional variety shrimp at the village measured at its most common grade; (2) village price of HYV and traditional post-larvae (seed); (3) the village price of one casual day of labor.

2.4.2.2 Mangrove (M)

The status of mangroves is measured with a binary variable that indicates the presence of mangroves along the village's coastline. This indicates the initial stock of mangroves and the level of erosion risk that is faced by the village. Villages that already have mangroves lining the coastline may have less incentive to plant mangroves than villages that do not have any at all. We control for variation in exposure to erosion risk by including this variable in analysis.

2.4.2.3 Village Institutional Characteristics (K)

This set of variables measures the institutional characteristics of the village: variables indicating presence of pre-existing village cooperative institutions, and governance mechanisms used by the village.

First, is a dummy variable indicating if the village has a shrimp producer organization. Producer organizations play an important part in the village in (1) the diffusion of market information and information regarding new technologies; (2) collective management of common-pool waterways like canals, rivers, and mangroves; (3) containing shrimp disease problems in production; (4) collectively marketing to access input and output markets. The existence of this institution indicates the increased interdependence of aquaculture farmers and a superior ability to manage common-pool resources. We hypothesize that villages with shrimp producer organizations will be significantly more likely to allocate labor to planting mangroves.

Second, is a dummy variable indicating if the village has a general shared labor cooperative called '*Gotong Royong*' in the village. This institution is a remnant of the Suharto era that was used primarily for the construction and management of irrigation infrastructure and also in organizing collective labor to plant and harvest rice. The hypothesis is that the existence of this institution plays an important role in: (1) facilitating and coordinating the efforts of many individuals; (2) internalizing the externalities of mismanaged mangrove resources; (3) improving access to cooperative labor pools in the village.

Third, we include a dummy variable that indicates if the village government has the power to impose sanctions (financial or otherwise) on village members that do not comply with village directives. Some villages use this institution to ensure participation in canal dredging or maintenance initiatives or imposing fines on members who violate a policy. While most villages rely only on the embedded cultural values and social relationships to enforce policy, those that employ sanctions may have a different ability to influence behavior of village members. The hypothesis here is that adding formal sanctioning institutions to the village's enforcement ability will help villages to coordinate individual agents to rehabilitating mangroves more effectively.

2.4.2.4 Village HYV technology diffusion (v)

In the village's mangrove-planting function, we summarize the technology employed by individual households in the individual by measuring the total population households in the village using each kind of technology, v. This is specifically measured with three village level population counts: (1) the population of all households in the village; (2) the population of shrimp farming households; (3) the population of HYV shrimp farming households.

$$v_t = \{Pop_{All}, Pop_{Shrimp}, Pop_{HYV}\}$$

These variables measure the level of heterogeneity in stakeholder group sizes and the aggregated preferences of each group.

The first variable is the population all households residing within the village's political boundaries. Higher populations may increase the propensity for villages to plant mangroves because the benefits of mangrove rehabilitation accrue to all members of the village regardless of how large or small the population is. Those with a larger labor pool may find it easier to recruit volunteer labor for the community. On the other hand, villages with larger populations may have more difficulty in communicating and organizing labor to plant mangroves, and suffer from a free-rider problem at the time of mangrove planting.

Second is a variable measuring the population of shrimp farm households in the village. The shrimp farm population is a subset of the village population, and with this variable we test the effect of shrimp farm population on the propensity to plant mangroves relative to the effect of non-shrimp farm village member. In the era of extensive expansion, shrimp farms were part of the mangrove deforestation that occurred (Barbier & Cox, 2004; Ron & Padilla, 1999), which suggests that this population will decrease the propensity to plant mangroves; however, when coastlines are bereft of mangroves, aquaculture households are most at risk and have incentives to protect their ponds by planting mangroves.

Third is a variable measuring the population of households in the village that have adopted the HYV technology in 2009. HYV adopting population is a subset of the shrimp farm population in the village, and with it we test the effect of HYV farms on the propensity to plant mangroves relative to the effect of a non-HYV farm. HYV adopting farms may value mangrove resources higher than the normal population of aquaculture households for two reasons: (1) The profit per hectare on their aquaculture ponds are higher; so they may value erosion mitigating mangrove barriers higher than non-adopting farms; (2) HYV adopting farmers have made significant irreversible investments into their ponds that are specific to HYV farming practices: (1) increasing the pond depth; (2) reshaping the pond floor; (3) and installing monitoring points. Farms with these investments may have more incentive in preventing erosion and protecting these investments.

2.4.2.5 Village Land (T)

In the village's labor supply function, we summarize household endowments of land in the village $T_{it}, \dots, T_{Nv}$ by describing the distribution of land in the village with three variables: (1) the average area of ponds farmed in the village; (2) the Gini coefficient measuring the concentration of pond area in the village; (3) the total length of the village's coastline.

$$T_i, \dots, T_{Nv} \approx T = \{\overline{T_i}, GINI_V, Coast_V\}$$

The effect of the land endowment is uncertain. While villages with large areas of land and long coastlines are at the higher risk and thus have higher incentives to invest into erosion mitigating mangrove resources, it also means that the cost are higher to plant mangroves on the larger area. The result of these variables depend on how the marginal benefits of mangrove planting increase relative to the marginal cost with respect to area and coastline length.

2.5 Estimation Method

In this section we discuss the method we use to estimate the village mangrove planting function in terms of the functional form of the supply function, and the estimator used to estimate the model parameters.

2.5.1 Functional Form & nonlinearity

To economize notation, we will express the variables p, M, K, D, T simply as X and leave our independent variable of interest (D), the population of HYV adopters, as a separate right-hand side variable. Following, we take a stochastic approximation of the investment equation, which leads to the following empirical specification:

$$Y_v^* = X_v\beta_1 + \beta_2 D_v + \varepsilon_v$$

Where v subscripts villages. We observe the dependent variable in the following binary way:

$$Y_v = \begin{cases} 1, & for\ Y_v^* > 0 \\ 0, & otherwise \end{cases}$$

2.5.2 Estimation with Instrumental Variables

In estimation we face a problem of endogeneity. HYV diffusion is endogenous with mangrove planting. When choosing to adopt HYV, shrimp farming households may take into consideration the future endowment of mangroves in their village's coastline; and choose to adopt after having observed Y_v.

To account for potential endogeneity, we draw from the exogenous variation of two instrumental variables (Z) in identifying the effect of HYV diffusion on investment into mangroves. The variables included in the HYV diffusion equation that are excluded from the mangrove planting function are $Z = \{Z_1, Z_2\}$:

(1) Z1: the first instrument is a dummy variable indicating if the village has a bank branch operating in the area. Bank branches can assist farm households in obtaining capital for shifting to the HYV variety, but will not affect if the village decides to coordinates a mangrove-planting program.

(2) Z2: the second instrument is a count of the total number of shrimp traders that operate in the village. The number of shrimp traders in the village will facilitate diffusion of HYV because these agents disseminate market information and information on shrimp production technology; but this population does not affect how the village decides to coordinates a mangrove-planting program.

The mangrove-planting equation is then estimated using the IV-probit estimator (Evans et al., 1992) to control for endogeneity in the variable D, the population of HYV adopters in the village, using the instruments discussed above. The equations we estimate are then:

$$H\begin{pmatrix} Y_v \\ D_v \end{pmatrix} = \begin{cases} 1[X_v\beta_1 + \beta_2 D_v >- \varepsilon_{1v}] \\ X_v\gamma_1 + \gamma_2 Z_v + \varepsilon_{2v} \end{cases}$$

Assuming the error term is distributed multivariate normal, the likelihood of observation *v* is:

$$\mathcal{L}_v(Y_v, D_v, X_v, Z_v; \beta, \gamma, \sigma, \rho) = \iint_{H^{-1}} \phi(\begin{bmatrix} \varepsilon_{1v} \\ \varepsilon_{2v} \end{bmatrix}, \begin{bmatrix} 1 & \rho\sigma \\ & \sigma \end{bmatrix})$$

We test to see if D_v is exogenous once the MLE has been obtained by testing if the ρ parameter is equal to zero using an asymptotic t-test (Wooldridge, 2010), and also conduct a test of overidentifying restrictions for the ivprobit estimator (Lee, 1991) using the stata routine written by Baum et al. (2010).

2.6 Descriptive results

In this section, we present means, standard errors, and the t-tests on the variables used in analysis. Detailed results are presented in Table 14 in the appendix. The salient results are highlighted in this section.

First, we find that 42% (32 out of 75) of the villages in our sample have executed mangrove-planting programs on their coastlines. This is a very high percentage and it demonstrates that coastal communities in Indonesia are actively engaged in planting mangrove forests and protecting valuable coastal land from the threat of erosion and subsidence. While mangroves have been severely degraded in Indonesia, rehabilitation of these forests appears to be underway in many villages.

Second, producer organizations and labor cooperatives appear to be facilitating mangrove planting. We find that (1) shrimp producer organizations were active in 94% of mangrove planting villages compared to 84% in non-planting villages; (2) 41% of mangrove planting villages have a labor pooling cooperative with only 16% among non-planting households. This suggests that these organizations may be an important factor in facilitating the planting of mangroves.

Third, the enforcement mechanisms wielded by the village appears to be a very important factor. While 31% of mangrove planting villages had the power to sanction village members for non-compliance, only 7% of village that were not planting mangroves had the same ability. The power to enforce may be an important factor in inducing village members to manage common-pool resources.

Fourth, we find that villages that planted mangroves also have 50% more HYV adopters than villages that did not plant mangroves. In contrast the total population of shrimp farmers is smaller (27) in mangrove planting villages when compared to non-planting villages (30). These results suggest that the farming technology employed by shrimp farming households is correlated to the planting of mangroves in the village.

Many factors can be correlated with HYV population and the village characteristics discussed in this section. In order to identify the independent effect of these variables holding all other things constant, we must turn to regression analysis to parse out each effect.

2.7 Regression Results

Complete regression results can be found in Table 15 and Table 17 in the appendix. In this section we discuss the salient results from IV probit estimation of the model parameters, of the mangrove labor equation, and also the reduced form HYV diffusion equation.

2.7.1 HYV diffusion equation

In the reduced form HYV diffusion equation, we find a number of interesting results (Table 14). First, villages with cooperatives tend to have higher levels of HYV diffusion. These cooperatives may be helping farmers in the village make labor investments to increase the pond depth, reshaping the pond floor, or installing monitoring points in order to shift to HYV shrimp production systems.

Second, villages with a bank branch, one of our instrumental variables, has a significant positive correlation with HYV adopting population in the village. This suggests that farm households may be facing credit constraints in the adoption of the HYV. Household without access to credit may not be able to make the necessary investments to intensify production practices by acquiring critical capital items like water-pumps and purchasing market inputs like HYV PL.

Third, the number of shrimp traders operating in the village, another instrumental variable, has a significant positive relationship with the HYV adopting population in the village. Having more shrimp traders operating in the village may be improving farmer access to information regarding how to market, where to procure inputs, and knowledge regarding production practices for the HYV.

Fourth, we test exogeneity of the shrimp HYV population variable by testing the null hypothesis that the rho parameter, endogeneity parameter, is equal to zero. We reject the null hypothesis (Table 16), which means the shrimp HYV population variable is endogenous and requires us to use the IV probit estimator.

Last, we test the over-identifying restrictions for the ivprobit estimator (Lee, 1991). The test yields a chi-square statistics of 0.07 (df=1), and we can conclude that the instruments are not correlated to the error term in the mangrove planting equation.

2.7.2 Mangrove planting equation

We find a number of interesting results in the mangrove planting equation (Table 17). First, we find that villages with higher populations of traditional shrimp aquaculture farmers were significantly less likely to invest into replanting mangrove resources. The marginal effect of one additional shrimp aquaculture farmer on the probability that the village allocates labor to plant mangroves is -1% (Table 18). This stakeholder group, on average, does not value the rehabilitation of mangrove resources and prefers not to expend labor resources to rehabilitate mangroves.

Second, we find a strong opposite result for the population of HYV adopters. Relative to traditional farmers, the HYV adopting population was found to have a positive and statistically significant impact on the probability that the village allocates labor to replanting mangroves. Converting one traditional farmer to a HYV farmer increases that propensity to plant mangroves by 4% (Table 18). HYV adopting farms may value mangrove resources higher than the rest of the population because: (1) they have higher profit per hectare on their aquaculture ponds, which they want to protect from the threat of erosion; (2) they may also have made significant irreversible investments into their ponds that they would lose to erosion.

These results already show that the diffusion of shrimp aquaculture technology is having a significant impact on mangrove forests along Indonesia's coastline. If communities remain farming the traditional variety, the mangrove forests may remain in their current state of degradation; on the other hand, inducing adoption of the HYV could lead to a significant increase in efforts to rehabilitate mangrove forests. One HYV farmer offsets the negative effects of three to four traditional farms.

Third, the presence of producer organizations in the village has a marginally significant relationship with mangrove replanting behavior in the village. Compared to villages without a producer organization, those with a producer organization were 35% more likely to invest into mangroves. This institution provides organization structure for individual shrimp farmers to coordinate behavior and improve the overall welfare as a collective. An important role that this organization is playing is in the rehabilitation of mangroves on coastlines.

Finally, the village's ability to impose sanctions on non-compliant village members was a significant factor related to the village's mangrove investment behavior. Compared to villages without the ability to sanction members, villages with this power were 36% more likely to invest into mangrove resources. The ability of a village to enforce its regulations with sanctions (ability to create credible threats) is an effective tool for governance, and this power is critical to the management of mangrove resources in the village.

2.8 Summary and conclusions

Mangroves are an important natural resource and are especially important for coastal communities because they keep loose coastal soils in place and prevent erosion of land and subsidence into the sea. In Indonesia, the mangrove forests are in a severely degraded state, but many villages throughout the country have been observed planting mangroves and attempting to rehabilitate these forests. This study examined the factors driving mangrove forest rehabilitation efforts, focusing specifically on how the diffusion of a new shrimp HYV technology is affecting how farm households and communities are allocating labor to revive valuable erosion mitigating mangroves.

We found that HYV adopting farms are significantly more likely than conventional farms to invest labor into rehabilitating the mangrove forests. The intensification of production and conservation of the environment are not necessarily mutually exclusive objectives. Some technologies, such as the HYV shrimp, can actually induce positive outcomes on natural resources. The introduction and diffusion of such technologies may be a more sustainable and cost-effective way to induce communities not only in curtailing exploitation of a natural resource but also in inducing its rehabilitation.

In addition, we find that village institutions are very important in the management of mangrove resources. Villages with shrimp producer organizations were 35% more likely to be planting mangroves. In addition, villages with the ability to impose sanctions were 36% more likely to plant mangroves. Improving the village’s ability to organize individual members and the ability to enforce policy appear to be effective ways to assist communities in rehabilitating mangrove resources.

While we have found a number of meso-level factors facilitating mangrove rehabilitation, very little is known regarding the household decision. Future research on mangrove rehabilitation should examine the household level decision to plant mangroves to determine what micro-level factors are driving or preventing individuals in the village from rehabilitating this natural resource.

APPENDIX

APPENDIX

Figure 4: Decision Tree

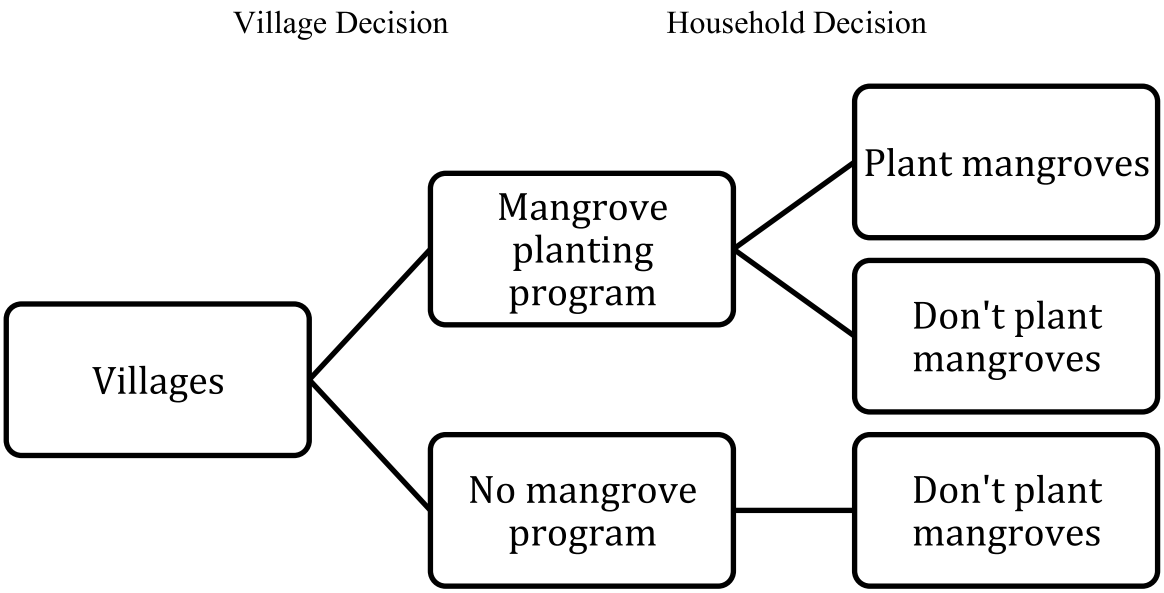

Table 14: Descriptive statistics by mangrove replanting status

VARIABLES	(1) Overall (μ)	(2) Non-planting (μ_N)	(3) Planting (μ_P)	(4) t-test
Population of HYV adopters (count)	4.37	3.58	5.44	
	(1.125)	(1.526)	(1.667)	
Village population of shrimp farms (count)	29.00	30.16	27.44	
	(3.354)	(4.894)	(4.380)	
Village population (10 count)	40.81	39.11	43.08	
	(3.725)	(4.858)	(5.865)	
Village has aquaculture producer organization (binary)	0.88	0.84	0.94	
	(0.038)	(0.057)	(0.043)	
Village has general labor cooperative (binary)	0.27	0.16	0.41	*
	(0.051)	(0.057)	(0.088)	
Pond area of village (ha)	1.99	1.87	2.14	
	(0.205)	(0.280)	(0.303)	
Concentration of pond area (Gini Coef.)	0.33	0.30	0.38	*
	(0.022)	(0.030)	(0.030)	
Village has mangroves on coastline (binary)	0.43	0.37	0.50	
	(0.057)	(0.075)	(0.090)	
Length of coastline (Km)	3.95	3.47	4.59	
	(0.376)	(0.419)	(0.669)	
Village shrimp output price (1000 IDR/Kg)	55.01	54.38	55.85	
	(0.915)	(1.192)	(1.435)	
Village price of HYV output (1000 IDR/Kg)	37.32	37.37	37.25	
	(0.708)	(0.927)	(1.112)	
Village shrimp input price (IDR/PL)	21.53	22.24	20.58	
	(0.435)	(0.511)	(0.728)	
Village shrimp HYV input price (IDR/PL)	24.69	25.43	23.71	
	(0.695)	(0.845)	(1.160)	
Village price of one labor day (1000 IDR/day)	31.23	30.78	31.84	
	(1.138)	(1.568)	(1.656)	
Village imposes sanctions for non-compliance (binary)	0.17	0.07	0.31	*
	(0.044)	(0.039)	(0.083)	
Village has bank branch (binary)	0.37	0.33	0.44	
	(0.056)	(0.072)	(0.089)	
Village population of shrimp traders (count)	1.83	1.47	2.31	
	(0.404)	(0.408)	(0.772)	

Standard errors in parentheses

* p<0.05 ($H_0: \mu_N = \mu_P$)

Table 15: HYV diffusion equation

VARIABLES	(1)
Village population of shrimp farms (count)	0.10**
	(0.039)
Village population (10 count)	-0.08**
	(0.038)
Village has aquaculture producer organization (binary)	-2.91
	(3.182)
Village has general labor cooperative (binary)	8.98***
	(2.410)
Pond area of village (ha)	-0.05
	(0.504)
Concentration of pond area (Gini Coef.)	8.74
	(5.499)
Village has mangroves on coastline (binary)	1.38
	(2.070)
Length of coastline (Km)	-0.46
	(0.332)
Village shrimp output price (1000 IDR/Kg)	0.08
	(0.147)
Village shrimp input price (IDR/PL)	0.40
	(0.289)
Village shrimp HYV input price (IDR/PL)	-0.07
	(0.271)
Village price of one labor day (1000 IDR/day)	0.11
	(0.133)
Village imposes sanctions for non-compliance (binary)	-2.37
	(2.817)
Brebes District (binary)	-2.33
	(2.955)
Bulukumba District (binary)	-1.82
	(3.734)
Barru District (binary)	-2.40
	(4.154)
Village has bank branch (binary)	4.17**
	(1.876)
Village population of shrimp traders (count)	0.51*
	(0.287)
Constant	-11.81
	(9.537)
N = 75	
Log-likelihood = 294.7	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16: Covariance parameters

Parameters	(1)
rho	-0.83**
	(0.178)
sigma	7.54***
	(0.617)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 17: Mangrove labor equation

VARIABLES	(1)
Population of HYV adopters (count)	0.09***
	(0.032)
Village population of shrimp farms (count)	-0.02***
	(0.007)
Village population (10 count)	0.01
	(0.006)
Village has aquaculture producer organization (binary)	0.86*
	(0.514)
Village has general labor cooperative (binary)	-0.45
	(0.598)
Pond area of village (ha)	0.15
	(0.111)
Concentration of pond area (Gini Coef.)	-0.03
	(1.055)
Village has mangroves on coastline (binary)	-0.15
	(0.339)
Length of coastline (Km)	0.09
	(0.062)
Village shrimp output price (1000 IDR/Kg)	0.03
	(0.027)
Village shrimp input price (IDR/PL)	-0.05
	(0.046)
Village shrimp HYV input price (IDR/PL)	-0.02
	(0.044)
Village price of one labor day (1000 IDR/day)	0.01
	(0.024)
Village imposes sanctions for non-compliance (binary)	1.04**
	(0.515)
Brebes District (binary)	0.21
	(0.474)
Bulukumba District (binary)	0.29
	(0.590)
Barru District (binary)	0.67
	(0.669)
Constant	-2.15
	(1.877)

N = 75
Log-likelihood = 294.7

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18: Marginal probabilities

VARIABLES	(1) Margins
Population of HYV adopters (count)	0.04
	(0.013)
Village population of non-adopting farms (count)	-0.01
	(0.003)
Village has aquaculture producer organization (binary)	0.35
	(0.169)
Village imposes sanctions for non-compliance (binary)	0.36
	(0.142)

Standard errors in parentheses

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Chapter 3: Allocative efficiency of shrimp traders in Indonesia

3.1 Introduction

One of the enduring themes in agricultural economics is Schultz's 'poor but efficient' hypothesis which posits that research on low-income agriculture "will not discover any major inefficiency in the allocation of factors" (Schultz, 1964). The objective of this study is to test this hypothesis for the first time among agricultural traders, an important segment of the rural economy and agricultural supply chains.

Allocative efficiency is achieved when a firm chooses the cost-minimizing bundle of inputs to produce a given quantity; the efficient firm chooses input quantities such that the value of marginal products are equal to the factor prices. In the neoclassical setting, allocative efficiency is assumed under the conditions of perfect information, risk neutrality, and zero transaction costs; but in the agriculture sector where conditions are farm from perfect, the neo-classical benchmark is difficult to achieve.

Traders operating in low-income agriculture contexts are constrained in achieving neo-classical allocative efficiency in the presence of (1) barriers to accessing relevant market information; (2) cash constraints and credit market failures needed to operate efficiently (3) risk in production or in prices; (4) poor institutional arrangements and settings with insecure property rights; (5) low human capital (Ali & Byerlee, 1991; Huffman, 1977). These factors reduce the allocative capacity of firms by adding transaction costs and risk premiums to the price of a factor inputs, leading firms to deviate from neo-classically efficient points.

Empirical studies on the micro-economics of traders have identified conditions that may lead to deviations away from allocative efficiency. First, Barrett (1997) identified the presence of credit market failures as a barrier to accessing high-profit markets for Malagasy traders. Second, research on social networks in the trade segment has found that social ties are related to many factors that determine allocative efficiency: (1) access to market information; (2) access to credit; (3) contract enforcement; (4) mitigation of risk in trade, and; (5) reducing costs (Fafchamps & Minten, 1999, 2001, 2002). Third, studies have found that risk in temporal arbitrage and product quality are causing traders to incur otherwise unnecessary costs (Fafchamps & Gabre-Madhin, 2001). Fourth, human capital in education was found to have mixed effects on income and trader margins (Fafchamps, Gabre-Madhin, & Minten, 2005; Minten & Kyle, 1999).

While past studies have found that that conditions for inefficient allocations are present and pervasive in many trader contexts, no explicit tests for allocative efficiency that stem from these conditions have been conducted. This may be due to data and methodological constraints. The popular primal approach to allocative efficiency analysis requires estimation of a production function to test if the value of marginal products is equal to its factor price (Chennareddy, 1967; Sahota, 1968). This is difficult in the context of a trader because it is difficult to quantify and consistently measure input and output quantities for a trader's varied production activities.

A dual approach that estimates a cost-function and the positive deviations from this function (Hazarika & Alwang, 2003; Nadolnyak, Fletcher, & Hartarska, 2006) is more feasible — exact input quantities do not need to be observed in the dual approach, however data on the market price for factor inputs and the output quantity of the firm is required. In addition, this method requires that the amount of value adding be the same (or held constant) for all traders so that the trade quantity is a consistent measure of the firm's production activity. This level of homogeneity is a rare context in agricultural trade as traders typically conduct differing levels of grading or processing to capture returns to these activities.

However, we find the rare case of standardized trade in the shrimp industry in Indonesia. Shrimp is an export commodity in Indonesia whose trade is highly standardized. All shrimp trade enterprises must perform a uniform minimum set of tasks to assemble, grade, and transport shrimp to meet international trade standard. In addition, there are no opportunities for traders to value-add by processing shrimp (peeling, deveining, beheading) because international food safety standards restrict processing to only certified shrimp processing plants. This means that allocative efficiency in trade can be isolated while holding constant value-added activities, which is a confounding factor in the analysis of many other trader contexts.

This study contributes to the literature by: (1) explicitly testing for allocative efficiency among agricultural traders using data from the authors' own survey of 200 shrimp traders in Indonesia; (2) using stochastic cost frontier analysis to evaluate the allocative performance of traders as it relates to: (i) scale of the firm; (ii) social capital; (iii) human capital; (iv) institutional arrangements; (v) specialization in trade. This paper specifically focuses on the following research questions:

RQ1: Does the scale of the trade firm affect its allocative efficiency?

Small-scale traders makeup most of the population in the trade segment, but their allocative performance relative to larger traders remains unknown. On one hand, larger traders may have: (1) better access to credit, labor markets, and output markets which affect allocative ability; (2) the ability to spread fixed transaction costs over a larger quantity thus improving access to markets and improving allocative efficiency. On the other hand, an empirical study by Fafchamps et al. (2005) found no scale effects on trader margins in Benin, Madagascar, and Malawi, which suggests that allocative efficiency is unrelated to scale.

RQ2: Does social capital affect the trader's allocative efficiency?

Access to markets, access to market information, contract enforcement, and risk mitigation is important in determining allocative efficiency, and all these factors have been found to be related to social capital in the trade segment (Fafchamps & Minten, 1999). Furthermore, social relationships have been found to increase the marketing margins in trade (Fafchamps & Minten, 2002). We hypothesize that social networks also improve the allocative efficiency of traders.

RQ3: Does vertical coordination affect a trader's allocative efficiency?

Institutional arrangements are an important determinant of allocative efficiency, and the use and breach of contracts in agricultural trade have been documented (Fafchamps & Gabre-Madhin, 2001). Variation in institutional arrangements with suppliers and with buyers may be an important determinant of allocative efficiency. To secure supply of intermediate input, shrimp traders sometimes offer credit in exchange for guarantee of supply. A trader may also have a contractual relationship with a buyer in the output market that ties their output to a specific buyer. The effects of these vertical arrangements on efficiency remain unknown. On one hand, these vertical arrangements may improve allocative efficiency due to reduced transaction costs in the respective markets and also reduced risk in prices over time. On the other hand, the trader must incur the cost of specifying and enforcing a contract and may sometimes have to forego more efficient opportunities to honor the contract.

RQ4: Does diversification in procuring from a specific market channel affect allocative efficiency?

The allocative efficiency of a firm may also depend on how diversified the firm's is in trading different varieties. On one hand, diversification could improve allocative efficiency because traders would have more market options from which to choose the optimum. On the other hand, the increase in market options comes at a price. Diversified farmers may incur higher search costs and there may be foregone gains to specialization. In farming, diversification in crops farmed was found to decrease technical efficiency (Llewelyn & Williams, 1996), but a parallel analysis has not been done examining the allocative efficiency of traders.

The rest of the paper proceeds in the following sections: (2) Data and sampling; (3) Theoretical model; (4) Model specification; (5) Empirical method; (6) Descriptive statistics; (7) Regression results; (8) Summary and conclusions

3.2 Data and Sampling

We implement our analysis using data from a survey of 200 shrimp traders conducted in Indonesia. Interviews were conducted in the months of February and March of 2012. This section discusses the design of the survey instrument and the survey sample.

3.2.1 Questionnaire design & development

The development of the questionnaire took place between October 2011 and February 2012. Pre-testing of the questionnaire was conducted as an iterative process where a questionnaire draft is tested and then revised with information obtained from the testing-round. During this stage, multiple questionnaire drafts were taken to the field and tested on a range of different traders in order (1) to correct confusing wording and simplify any concepts that were not readily understood by a respondent. This means using local vocabulary and sometimes restructuring of questions so that farmers could answer accurately and promptly; (2) to reduce the complexity of the questionnaire structure for ease of use by enumerators and reduce error in enumeration; (3) to make the questionnaire flow and transition in order to make the interview process easier to conduct; (4) edit and revise questionnaire in response to any new information acquired from pre-test respondents.

The final questionnaire collects data on: (1) characteristics of the trader; (2) capital and depot area endowments of the trader; (3) the costs of input procurement and output marketing; (4) the prices of factor and intermediate inputs; (5) quantities of shrimp traded.

3.2.2 Sample Design

The sample is drawn from two provinces from a total of four major shrimp trading districts in Indonesia. The geographic distribution of the sample is as follows:

3.2.2.1 Province Selection

To select the provinces in which to administer our survey of shrimp trade enterprises, we set out to choose two provinces that represent the two economic settings in Indonesia: (1) Developed and; (2) Hinter-island.

Developed provinces are composed of shrimp producing regions characterized by rural communities with: (1) dense populations in rural villages; (2) good public infrastructure in canals, roads, and public utilities; (3) more developed and diversified economies with easier access to factor markets.

Hinter-island shrimp aquaculture provinces are characterized by: (1) low population densities; (2) poor public infrastructure, with poor roads, deteriorated canals, and no electricity; (3) much less diversified rural economy that relies almost entirely on agricultural production.

We selected one province of each type to represent the two different types of shrimp producing provinces that exist in Indonesia. The provinces chosen are Central Java and South Sulawesi.

3.2.2.2 Central Java (CJ)

We choose Central Java to represent the “developed” shrimp provinces of Indonesia that are typically to the island of Java, the most populated island of Indonesia.

Central Java is a province located in the middle of the Indonesian island of Java. This province has a long history of trade in shrimp. The major areas of trade in Central Java are located along the northern coast and nearby the major interstate highway that connects Jakarta, the primary port of Indonesia, with Surabaya, the second largest port. Rural and urban areas on the island of Java are more developed, and more commercialized than those encountered in other islands such as Sulawesi.

3.2.2.3 South Sulawesi (SS)

We choose South Sulawesi to represent the "hinter-island" shrimp aquaculture producing provinces of Indonesia that are found off of the island of Java and are less densely populated compared to Java.

South Sulawesi province is located on the southwestern part of the island of Sulawesi (Celebes). The main areas of shrimp trade in South Sulawesi are located along the western cost of the province, and are typically near the Trans-Sulawesi highway that connects cities and rural hubs to the major port of Makassar. Rural economies in South Sulawesi are generally less developed compared to those found on the island of Java. Rural economies still revolve primarily around agricultural production with fewer opportunities to diversify into non-farm activities.

3.2.3 District Selection

Within each selected province, we chose two districts that represent two different types of shrimp production zones: (1) Districts that are close to a major city or port; (2) Districts that are far from a major city or port. One of each type of district was selected from each province giving a total of 4 districts in our sample.

3.2.4 Census of shrimp traders & sample

To obtain a population listing of shrimp traders in each of our chosen districts, a census of shrimp traders was conducted. We began by consulting each district fisheries office to obtain a list of all villages, markets, and warehouse areas where shrimp traders are located. This list of shrimp trader areas was verified to be exhaustive for each district by consulting local extension agents, leaders of producer organizations, and industry actors. For each area on this list, enumerators conducted a census of all shrimp traders located in the district to generate a population listing of all traders.

From the census of shrimp traders in our selected districts, we drew a sample of 65 traders in South Sulawesi province and 135 traders in Central Java province. Because the level of randomization is at the district level, generalizations of findings should be restricted to the boundaries of the districts.

3.3 Theoretical Model

To model the behavior of the trade enterprise, we begin with the model of a trade firm whose objective is to minimizes cost by choosing factor input quantities, x, given a set of market prices, P.

$$\min_{x} P'x$$

Subject to: $q = f(x, K)$

The trader is subject to: (1) producing quantity, q, and; (2) the production function f(x,K). To produce q units of output, the trader is bound to the production technology, f, that is a function of the variable factors inputs, x, and fixed capital inputs, K, that cannot be adjusted in the short-run.

The production function of a shrimp trader is different from conventional production functions. The production activity of a trade firm is to produce an intangible output that is embedded as a product attribute in the shrimp quantity traded. The trader's production activity is providing a service to transform raw material shrimp into shrimp that is (1) purchased from the optimum set of suppliers; (2) assembled; (3) sorted and graded; (4) packaged; (5) loaded; (6) transported; (7) unloaded, and; (8) marketed to the optimum output channel. The production of the services to embed these attributes is exactly proportional to the quantity of shrimp that is traded by the firm because each unit of shrimp is embedded with identical attributes. Thus, we can interpret the throughput of the trade firm to be equivalent to the quantity of trade services rendered, which we represent with the variable q.

The trader's problem can then be represented with optimization of the following lagrangian expression.

$$\mathcal{L} = P'x + \lambda[q - f(x, K)]$$

After differentiating the lagrangian with respect to the control variables, x, and manipulating the first order conditions, we can derive the minimum-cost function, which represents the lowest possible cost that a firm can incur to trade quantity, q. The function depends on prices, P, output quantity, q, and fixed inputs, K.

$$C(P, q, K)$$

To model deviations from the cost-minimizing point, we add two terms to the cost function: (1) v_i is exogenous variation to the cost that cannot be managed; (2) u, is a positive deviation away from the cost-minimizing point that are a result of suboptimal allocation decisions. The magnitude of u represents the additional cost that was incurred by the trader that resulted from their misallocation.

$$C(P, q, K) + v + u(z)$$

u, is a function of variables, z, that measure heterogeneity in the factors that give rise to allocative inefficiency. These are variables that measure differences in: (1) transaction costs in search, measurement, bargaining, and enforcement; (2) riskiness of trade, and; (3) human capital.

Allocative inefficiency in our model are deviations from the neo-classical condition of equating factor price to its value of marginal product. These deviations are a combination of true allocative inefficiency, and also rational deviations from the short-run cost-minimizing point. For example, trade firms may be incurring additional cost to setup and maintain contracts or relationships with supplier in order to maintain a consistency in the supply quantity. This would be a rational deviation away from neo-classical efficiency used as a strategy to maximize profit in the long-run. Such deviations demonstrate the nature of transaction costs in shrimp trade and the tradeoffs being made with more directly observable costs.

3.4 Model Specification

In this section we describe the variables used in cost frontier analysis. We begin by describing the dependent variable, followed by our specification of cost function arguments, and conclude the section with a discussion on variables that are determining the allocative efficiency of trade operators.

3.4.1 Dependent Variable (trading cost)

We measure and specify two measures of cost of the firm. First, we measure the total weekly cost of operating the trade firm. This is the cost of (1) the labor used to sort, grade, package, load, transport, unload, and market shrimp; (3) the cost of gasoline, tolls, and services used to transport shrimp, and; (4) cost of cellular phone minutes used to coordinate the transaction. It does not include payment for factors that cannot be adjusted within a one-week time frame such as warehouses, vehicles, and equipment.

Second, we divide this total cost by the total quantity traded in one week to yield the unit-cost of trade. This is the average per-kilo cost incurred to trade shrimp, starting from the procurement all the way up to final sale for a week of trading. We utilize the unit-cost form of the cost variable to facilitate testing the scale effect in allocative efficiency.

3.4.2 Explanatory Variables

The cost frontier is a function of prices, and fixed capital. The variables we include in estimation of the cost frontier are discussed in this section. We begin with prices.

3.4.2.1 Input prices (P)

We specify the cost function to depend on the following prices:

First, we include the price for one day of casual labor. Casual labor is one of the most important inputs in the shrimp trade enterprise and the ability of the firm to hire the cost-minimizing number of casual laborers for a given shrimp transaction may be one of the key factors in the firm's performance in minimizing costs.

Second, we include the distance required to travel to make the transaction. Because the government controls the prices of fuel and tolls, there is no variation in transportation prices in our sample and we must draw on variation in the distance travelled in order to control for heterogeneity in the transportation costs incurred by the trader.

In line with theory, the cost frontier is expected to be non-decreasing with respect to input prices. That is, the parameters for the price variables are expected to be positive in the cost frontier estimation.

3.4.2.2 Capital (K)

We specify the cost function to depend on the following fixed capital items that the firm cannot adjust in the short-run. We specify three different types of capital that are fixed in the short-run.

First, we include a standardized index of productive capital items. Capital items used to construct the index are scales, storage containers, cold storage equipment, and cellular phones. The index is constructed using factor analysis that uses the covariance of capital items included in the index to reduce the dimensions of the data, which in this case reduces simply to one principal direction. The magnitude of the capital index measures the overall capital endowment of the trade firm, with high values indicating high capital endowments and low values indicating low endowment.

Second, we include another standardized index of transportation assets. The items used to construct this index are trucks, pickup trucks, cars, and small transports. The index measures the amount of transportation equipment that the trade enterprise owns. It is constructed using the same method as the productive capital index.

Third, we include the area of the trade depot used by the trader to assemble shrimp. Depots are used to assemble shipments from multiple sources, serve as a facility to grade and sort shrimp, and also as a storefront. This variable measures the total area, in square meters, of the trade depot that the trader either owns or rents.

We hypothesize that the endowment of all capital items will decrease trading costs as these items can be substitutes for labor inputs used to trade shrimp. We expect that the cost frontier will be non-increasing with respect to these variables.

3.4.3 Determinants of allocative inefficiency (Z)

Variables used to model allocative inefficiency fall into four categories: (1) Operator characteristics; (2) Social capital; (3) Diversification in trade, and; (4) scale of the trade enterprise.

3.4.3.1 Operator characteristics

To control for operator characteristics in the determinants of allocative efficiency, we include two variables in analysis.

First, we include a dummy variable indicating if the trade operator is female. The gender of the household may be imposing additional transaction costs on the firm. Women may have more difficulty in accessing shrimp producers and fishermen who are predominantly male, accessing labor markets in her area to hire casual laborers, and in the marketing of output. Gender is particularly important in the trade segment because the high prevalence of women operated firms relative to agricultural production. Half of the traders in Madagascar (Fafchamps & Minten, 1999), 80% of traders in Benin, and 36% of traders in Malawi were female operated (Fafchamps et al., 2005). Past studies on the technical efficiency of farm household has found that women and men are equal in technical efficiency, but there is evidence of allocative inefficiency for female managed plots (Quisumbing, 1996; Udry et al., 1995). However, the difference in allocative efficiency between the two genders has not been studied before in the trade segment.

Second, we include the educational attainment of the trade enterprise's operator measured by years of formal education completed. Past research has shown that education leads to higher levels of technical and allocative efficiency in agricultural production. We hypothesize that education will improve allocative efficiency in agricultural trade as well.

3.4.3.2 Social Capital

We include a dummy variable indicating if the trade enterprise had any neighbors or relatives in the upstream segments in the shrimp industry (processor, exporter, retail). Trade enterprises that have ties to downstream agents in the shrimp industry may have an advantage in access to information and have improved access to output markets because of this relationship and the reputation that is embedded.

Access to markets, access to market information, contract enforcement, and risk mitigation is important in determining allocative efficiency, and all these factors have been found to be related to social capital in the trade segment (Fafchamps & Minten, 1999). Social capital with downstream segments is particularly important as this is where market access barriers are greatest. With social ties to a downstream agent, a trader will have: (1) lower cost and more timely access to information on market conditions which will allow them to make allocation decisions more efficiently, and; (2) lower cost of bargaining in the output market because of the reputation invested in the social relationship. With reduction in these transaction costs, the trader may be able to reallocate labor and reduce the costs of trade.

3.4.3.3 Diversification of trade

We measure diversification in varieties traded with a dummy variable that indicates if the firm trades only one variety of shrimp. The net effect of diversification on allocative efficiency depends on the tradeoff between having a larger opportunity set, versus gains to specialization in trading a single variety. On one hand, trading multiple varieties means that traders can choose from a larger set of suppliers and buyers to transact with, and a larger opportunity set will increase allocative efficiency. On the other hand, diversification in varieties could result in lower efficiency because of foregone gains to specialization. Specialized traders may have better access to markets for their variety of specialization, and also have better access to information for their variety regarding: (1) prices at the farm-gate and output market; (2) times of harvest in different production areas, and; (3) timetables for when shrimp fishermen arrive in port.

3.4.3.4 Firm Scale

We include a measure of the trade enterprise's scale of operation. This is measured by the natural log of the firm's monthly throughput in kilograms of shrimp. There is a large diversity in the scale of firms in the shrimp trade segment. While there are numerous traders that trade small quantities (less than one MT per month), there are also a number of large traders with high throughput.

The scale of the trade firm may be affecting their cost efficiency. On one hand, larger traders may have higher allocative efficiency because of: (1) better access to credit, labor markets, and output markets which affect allocation of factors; (2) the ability to spread fixed transaction costs over a larger quantity thus improving access to markets and improving allocative efficiency. On the other hand, Fafchamps et al. (2005) find no scale effects on trader margins in Benin, Madagascar, and Malawi, which appears to suggest that scale is not an important factor that determines performance in the trade segment. We test for the scale effect in allocative efficiency in agricultural trade.

3.4.3.5 Institutional arrangement

In shrimp trade, input procurement and output marketing transactions are categorized into two categories: (1) spot-market arrangements, and; (2) contracted arrangements. We include two dummy variables to capture differences in the institutional arrangements used by traders. First, is a dummy variable indicating if the firm uses upstream contracts to secure an input source.

Second, is a dummy variable indicating if the trader uses downstream contracts to secure an output market.

The net effect of contract use on allocative efficiency will depend on: (1) the net transaction costs of using a contract relative to the cost of using a spot-market arrangement. The use of a contract may reduce search cost, reduce bargaining costs, and help traders overcome market access barriers through provision of credit or inputs. But contracts could result in higher enforcement costs compared to spot arrangements; (2) the relative risk of using a contract versus a spot-market arrangement. While using a contract may reduce risk in making transactions, it means foregoing opportunities to transact with agents that may be more efficient.

3.5 Empirical Method

In empirical implementation, we model the cost function in two forms. First is the conventional form that we derived that maps output quantity, prices, and fixed inputs to the total cost of operation. This function is given as:

(1) Total weekly cost: $C(P_i, q_i, K_i; \beta)$

Where C is the function representing the lowest cost possible given observation i's prices (P), weekly quantity traded (q), fixed inputs (K), and a vector of cost function parameters (β).

Second, is the unit-cost form of the cost function, which maps prices, quantity traded, and fixed inputs to the per-unit cost of trade. This function is given as:

(2) Average cost/Kg: $g(P_i, q_i, K_i; \gamma)$

Where g is the function representing the lowest unit-cost possible given observation i's prices (P), weekly quantity traded (q), fixed inputs (K), and vector of unit-cost function parameters (γ)

3.5.1 Stochastic Cost Frontier

Stochastic frontier analysis (SFA) is a parametric statistical approach to efficiency analysis (Aigner et al., 1977; Kumbhakar & Lovell, 2003). It decomposes the realized cost of a firm into three components: (1) the cost frontier; (2) allocative inefficiency component, and; (3) exogenous variation.

In implementation, SFA requires that we make three specifications to identify model parameters: (1) a specification of the functional form of the cost-frontier; (2) a specification of the distribution of the allocative inefficiency term, u; (3) a specification of the distribution of the error term, v.

We use the common specification of: (1) a cobb-douglass cost frontier; (2) normal distribution of the disturbance term, v; (3) the half-normal heteroskedastic distribution of the one-sided inefficiency disturbance term, u; (4) independence of u and v.

(1) Total Cost: $C(P,q,K;\beta) = \sum_{j=1}^{k} \beta_j \ln(P_j) + \beta_{k+1}\mathrm{K} + \beta_{\mathrm{k+2}}\mathrm{q_i}$

Unit Cost: $g(P,q,K;\gamma) = \sum_{j=1}^{k} \gamma_j \ln(P_j) + \gamma_{k+1}\mathrm{K} + \gamma_{\mathrm{k+2}}\mathrm{q_i}$

(2) $v_i \sim N(0, \sigma_v^2)$

(3) $u_i = \sigma_u |U_i|,\ U_i \sim N(0,1)$

(4) $E\left(u_i u_j\right) = E\left(v_i v_j\right) = 0,\ for\ i \neq j$

The causes of inefficiency are modeled as heteroskedasticity in u that depend on a set of variables, z, that determine inefficiency. We use the exponential specification (Coelli, 1995) of the heteroskedasticity as follows:

$$\sigma_{ui}^2 = \exp(z_i \theta) \tag{5}$$

Where θ is a vector of parameters to be estimated that model the allocative inefficiency in trade. The log-likelihood function for observation i is:

$$\ln\mathcal{L} = \sum_{i=1}^{N}\left[-\frac{1}{2}\ln(2\pi) - \ln(\sigma) - \ln\left(\Phi\left(\frac{z_i\theta}{\sqrt{\sigma^2\lambda}}\right)\right) + \ln\left(\Phi\left(\frac{(1-\lambda)z_i\theta - \varepsilon_i}{\sqrt{\sigma^2\lambda(1-\lambda)}}\right)\right) - \frac{1}{2}\left(\frac{\varepsilon_i + z_i\theta}{\sigma}\right)^2\right]$$

Where:

$\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$; $\lambda = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$; $\varepsilon_i = C_i - g(P_i, k_i; \gamma)$; and $\Phi(\cdot)$ is the standard normal cumulative distribution function.

3.5.2 Data envelope analysis robustness check

The main drawback of the SFA approach is that identification could hinge on a functional form assumption for the cost function. To test the robustness of the results from SFA, we will compare results from the non-parametric Data Envelope Analysis (DEA) approach, which is a programming method that does not impose a functional form assumption (Ramanathan, 2003).

DEA does, however, assume a deterministic cost frontier where there is no exogenous variation in cost. Comparing results from DEA and SFA, we can see how much our results change under two different sets of assumptions:

(1) DEA: no assumption of functional form, assumption of zero exogenous variation in cost

(2) SFA: assumption of functional form, allows exogenous variation in cost

DEA proceeds in two steps. First, DEA calculates the cost-frontier and allocative efficiency measures, which is done by linear programming that forms a piecewise hull (frontier) encompassing the data. The surface of the hull is composed of benchmark firms that lie on the frontier, and linear combinations of these efficient firms to form a surface. The magnitude of allocative inefficiency is calculated as the distance between this cost-frontier and a firm's realized cost.

Second, the allocative efficiency measures calculated using the DEA algorithm are regressed on a set of variables hypothesized to determine inefficiency. A truncated regression is used because all benchmark firms are expressed as being fully-efficient, and the distribution of inefficiency is specified to follow a half-normal distribution, just as in SFA.

3.6 Descriptive Statistics

In this section we present salient descriptive statistics results of the variables we will utilize in stochastic cost frontier analysis. Detailed results reporting means and standard deviations are presented in Table 20 through Table 22.

3.6.1 Transaction quantities and costs

First, the quantity of shrimp traded by a trader varies greatly in our sample. The mean of the distribution is 659 Kg / week. The distribution of weekly throughput (figure 1) shows that the scale of the enterprise is a skewed distribution with a mode at around one ton, but a long tail that extends all the way up to 5 metric tons.

Second, it is also interesting to note that there is a large gender differential. While most trade enterprises operated by women tend to be clustered in the low range, the trade enterprises operated by men tend to be larger. If there are efficiencies of scale, the discrepancy in firm scale may be affecting poorer performance in women and we must control for this to identify the effect of gender on allocative efficiency independent of scale efficiencies.

Third, traders do not incur very much cost in trade. The average cost of trading one kilogram of shrimp is 1,487 IDR ($0.15 USD) in our sample, which is only 2% of the farm-gate price of shrimp. In addition, there is a large spread in the costs per kg in trade. Figure 6 shows that the mode of unit costs is just under 1000 IDR and a tail that goes out to 3000 IDR.

3.6.2 Trader characteristics

First, a high proportion of traders were utilizing contracts in trade. 40% of traders were using upstream contracts to procure inputs, and 23% of traders were using downstream contracts to sell output. It appears that there is a tradeoff between unit-cost of trade and securing a market for inputs and outputs with contracts: (1) traders using contracts for both inputs and outputs were trading over 3MT, while traders not utilizing any contracts were, on average, trading only 155Kg per week; (2) traders utilizing contracts incurred more costs in trade compared to those not utilizing any contracts.

Second, a very large proportion of traders (32%) were trading only one variety of shrimp. There appears to be a scale and cost advantage for specialization in trade. Traders that were specialized in trading one variety traded 260 Kg per week, which is significantly lower than the 848 Kg per week traded by diversified traders. However, the costs of trade per kg were very similar despite the fact that specialized traders had less capital, transportation capital, trade depot area, and faced higher wages for labor.

Third, we find that the role of women in trade is large. Results show that women operate 43% of shrimp trade enterprises in Indonesia. The high incidence of female operated trade enterprises has also been found in previous studies (Fafchamps et al., 2005; Fafchamps &

Minten, 1999). This provides an opportunity to compare the relative performance of these two genders in trading shrimp.

Fourth, education is important in trade. On average, shrimp traders have seven years of formal education, which is higher than the national average of 6 years (UNDP, 2011). This suggests the importance of education in the operation of shrimp trade enterprises. But there are gender inequalities. In our sample, males have more education (7.7 years) compared to females (6.1 years) on average. The discrepancy in educational attainment may be affecting poorer allocative performance.

Fifth, a large proportion of traders (38%) had a neighbor or a relative in the downstream segments of the shrimp industry. Those with this social capital traded twice the volume of those without. In addition, traders with better social connections downstream tended to have significantly more capital, transportation capital, and depot area.

3.7 Regression Results

Detailed regressions results from maximum-likelihood estimation are presented in Table 23 and Table 24. In this section we present and interpret the salient results starting with the parameters of the cost frontier followed by the parameters used to model allocative efficiency.

3.7.1 Cost Frontier

Estimation of the cost frontier yielded normal results. First, our estimated cost frontier satisfies the conditions of non-decreasing cost with respect to the labor price. In addition, the distance travelled significantly increases the cost of trade. We also find that firms with a higher trade volume have lower costs per kilogram of trade.

3.7.2 Allocative Inefficiency

In this section we present the salient results in estimation of parameters modeling the allocative inefficiency. Overall results show that the average level of inefficiency show that on average, traders are incurring costs that are 15% higher than the lowest cost possible. The level of inefficiency in the sample ranges ranges from 2% to 65%.

3.7.2.1 Gender and Education

We find that traders with higher education are more allocatively efficient. The effect of schooling affects how traders are able to allocate factor inputs to achieve the lowest cost in trading shrimp. This corroborates evidence from previous studies on technical and allocative efficiency. When we explicitly control for the discrepancy in educational attainment by including the education variable, our results also show that female traders are not distinguishable from men in allocative efficiency.

3.7.2.2 Social Capital

We find that social capital is an important determinant of allocative efficiency. Traders that are socially networked with downstream segments of the value chain are significantly more allocatively efficient. This result corroborates evidence from previous studies that found an increase in marketing margins from social capital (Fafchamps & Minten, 2001, 2002); our result posits that this increase in margins is, at least in part, stemming from a higher allocative efficiency.

Traders that are connected with upstream agents are more aware of when processors receive large orders and ramp up demand, and more nuanced information on how much labor is required meet the minimum requirements for grades. In addition, these relationships may be reducing search costs in shrimp output markets. With improved access to this type of information and improve access to output markets, shrimp traders will are more able to coordinate labor, reduce communication cost, and consolidate shipments to minimize the cost of trade.

3.7.2.3 Diversification of trade

We find that traders that are specialized in one shrimp variety are more allocatively efficient than those that are diversified in procuring multiple types of shrimp. This is because specialization into a procurement variety means a trader will have invested more knowledge to reducing the costs of procuring and marketing that specific variety. This knowledge includes: (1) increased awareness of how much grading and sorting is required for the variety; (2) increased awareness of when specific farmers of that variety in their catchment zone will be harvesting; (3) more specific knowledge regarding the output markets associated with their variety of specialization. The benefits of specialization are outweighing the benefits of the diversification and an expanded opportunity set in procurement.

3.7.2.4 Scale of the firm

We find that there are scale effects in allocative efficiency. Larger firms were significantly more allocatively efficient compared to smaller firms. This may be a result of two factors: (1) there are fixed costs associated with accessing casual labor markets. Larger firms are more capable at dispersing these fixed costs and thus more able to adjust labor quantities while small firms are more constrained to the availability of casual labor in their village; (2) The substitution surface for higher isoquants are smoother than those for lower iso-quants due to the discrete nature of labor and capital inputs. The discreteness will result in poorer allocative performance among small operators.

3.7.2.5 Institutional arrangements

We find that traders that utilize contracts with upstream shrimp suppliers are significantly less allocatively efficient, while we find that traders utilizing contracts with downstream agents are significantly more allocative efficient.

This is because: (1) the trader faces significantly more risk in the output market compared to in the input market. After purchase, the trader must find a suitable market quickly for the highly perishable shrimp, and must incur high cost in search if there are any bottlenecks in marketing output. This risk can be mitigated with a downstream contract. Once an output market is secure, the trader may be more willing to hire labor, scale up, and reduce output market search costs to achieve a lower cost of trade; (2) being tied by an upstream contract may be forcing a trader to purchase shrimp at a time and place that is less than optimal for the trader. Contracts with a supplier may be reducing the ability of traders to efficiently pool shipments across time and space to achieve economies of scale in transportation. Upstream contracts are most likely used to ensure a consistent input supply, the benefits of which are not captured in an analysis of short-run cost-minimization.

3.7.3 Robustness of results

To test the robustness of the results we obtain from SFA, we compare them with results from the linear programming DEA method that does not assume a functional form of the cost-frontier. Results from DEA are similar to results from SFA, and demonstrates that results are not driven solely by the functional form assumption.

3.8 Summary and Conclusions

The objective of this study is to examine the allocative efficiency of agricultural traders using data form the author's own survey of 200 shrimp traders in Indonesia. This study has found that:

First, shrimp traders are not operating at the efficient frontier. There is evidence for significant allocative inefficiency among traders. The magnitude of inefficiency is not large, but gives significant room for improvement as the average level of inefficiency is 15% or about 220 IDR ($0.02 USD/Kg).

Second, there are scale efficiencies in trade. Larger firms are significantly more allocatively efficient than small firms. This explains the reported concentration that is occurring in the shrimp trade segment, and in the trade segment of other commodities in Indonesia.

Third, social networks with downstream agents significantly increase allocative efficiency in trade. The trader's ability to utilize social networks to obtain relevant information and improving access to output markets is allowing them to be more efficient in reducing the cost of operation.

Fourth, traders that are specialized in one shrimp variety are more allocatively efficient than those that are diversified in procuring multiple types of shrimp. The gains to specialization in the trade outweigh the cost of foregone opportunities in trading multiple varieties.

Fifth, not all contracts are equal. The use of contracts with upstream suppliers significantly reduced allocative efficiency while use of contracts with downstream buyers significantly increased allocative efficiency. Securing an output market for a perishable product is more beneficial than securing a source of the perishable product that is difficult to market.

APPENDIX

APPENDIX

Table 19: Sample totals

	Java	Sulawesi	TOTAL
Zone 1: Near Port	80	40	120
Zone 2: Distant Port	55	25	80
TOTAL	135	65	200

Table 20: Descriptive Statistics - Trader Operator Characteristics

VARIABLES	(1) Overall	(2) Male	(3) Female
Upstream contract (binary)	0.40	0.45	0.33
	(0.036)	(0.049)	(0.053)
Downstream contract (binary)	0.23	0.35	0.07
	(0.031)	(0.047)	(0.030)
Specialized in one variety only (binary)	0.32	0.37	0.25
	(0.034)	(0.047)	(0.049)
Social capital downstream (binary)	0.38	0.60	0.09
	(0.036)	(0.048)	(0.032)
Education of the trader (years)	6.79	7.38	6.03
	(0.212)	(0.285)	(0.299)
Observations	184	104	80

Table 21: Descriptive Statistics by specialization and social capital

VARIABLES	(1) Overall	(2) Specialized	(3) Not specialized	(4) Social Capital	(5) No Social Capital
Cost per kg (IDR)	1,487.28	1,595.49	1,436.15	1,767.76	1,319.47
	(112.611)	(202.799)	(135.650)	(199.304)	(133.095)
Total quantity traded (Kg)	659.99	260.83	848.57	1,052.27	425.30
	(182.034)	(77.915)	(264.202)	(469.346)	(72.508)
Price of traditional shrimp size 30/kg (1000IDR/Kg)	72.04	69.43	73.27	60.79	78.78
	(0.986)	(1.972)	(1.101)	(1.187)	(0.971)
Price of HYV shrimp size 60/kg (1000IDR/Kg)	41.63	40.86	41.99	37.70	43.98
	(0.727)	(1.433)	(0.832)	(1.053)	(0.913)
Price of one casual labor day (1000 IDR/Day)	43.63	47.09	41.99	53.09	37.96
	(3.269)	(3.398)	(4.540)	(8.347)	(1.363)
Transportation capital of firm (Index)	0.00	-0.03	-0.00	0.51	-0.32
	(0.071)	(0.064)	(0.101)	(0.165)	(0.032)
Productive capital endowment (Index)	0.00	-0.09	0.00	0.30	-0.22
	(0.071)	(0.044)	(0.088)	(0.122)	(0.058)
Area of trading depot (m2)	14.61	7.38	18.02	19.81	11.50
	(4.212)	(2.759)	(6.049)	(4.394)	(6.195)
Observations	187	60	127	70	117

Table 22: Descriptive Statistics by contract use

VARIABLES	(1) Overall	(2) No contract	(3) Upstream Contract	(4) Downstream Contract	(5) Both Contracts
Cost per kg (IDR)	1,487.28	1,127.50	1,622.70	1,405.08	2,923.64
	(112.611)	(137.643)	(205.323)	(287.110)	(465.470)
Total quantity traded (Kg)	659.99	155.03	198.55	1,627.00	3,139.44
	(182.034)	(15.853)	(24.575)	(463.248)	(1,657.074)
Price of traditional shrimp size 30/kg (1000IDR/Kg)	72.04	72.60	69.94	76.76	69.06
	(0.986)	(1.599)	(1.427)	(3.015)	(2.192)
Price of HYV shrimp size 60/kg (1000IDR/Kg)	41.63	41.32	39.37	46.91	42.49
	(0.727)	(1.077)	(0.718)	(3.069)	(1.793)
Price of one casual labor day (1000 IDR/Day)	43.63	35.52	50.00	52.63	49.97
	(3.269)	(1.315)	(10.071)	(6.016)	(6.294)
Transportation capital of firm (Index)	-0.01	-0.31	-0.11	0.76	0.66
	(0.071)	(0.034)	(0.052)	(0.326)	(0.437)
Productive capital endowment (Index)	-0.03	-0.32	-0.07	0.54	0.71
	(0.061)	(0.023)	(0.044)	(0.276)	(0.385)
Area of trading depot (m2)	14.61	2.02	6.34	49.00	51.50
	(4.212)	(0.548)	(1.242)	(26.612)	(15.855)
Observations	187	87	56	26	18

Figure 5: Distribution of transaction quantity by gender (Kg / week)

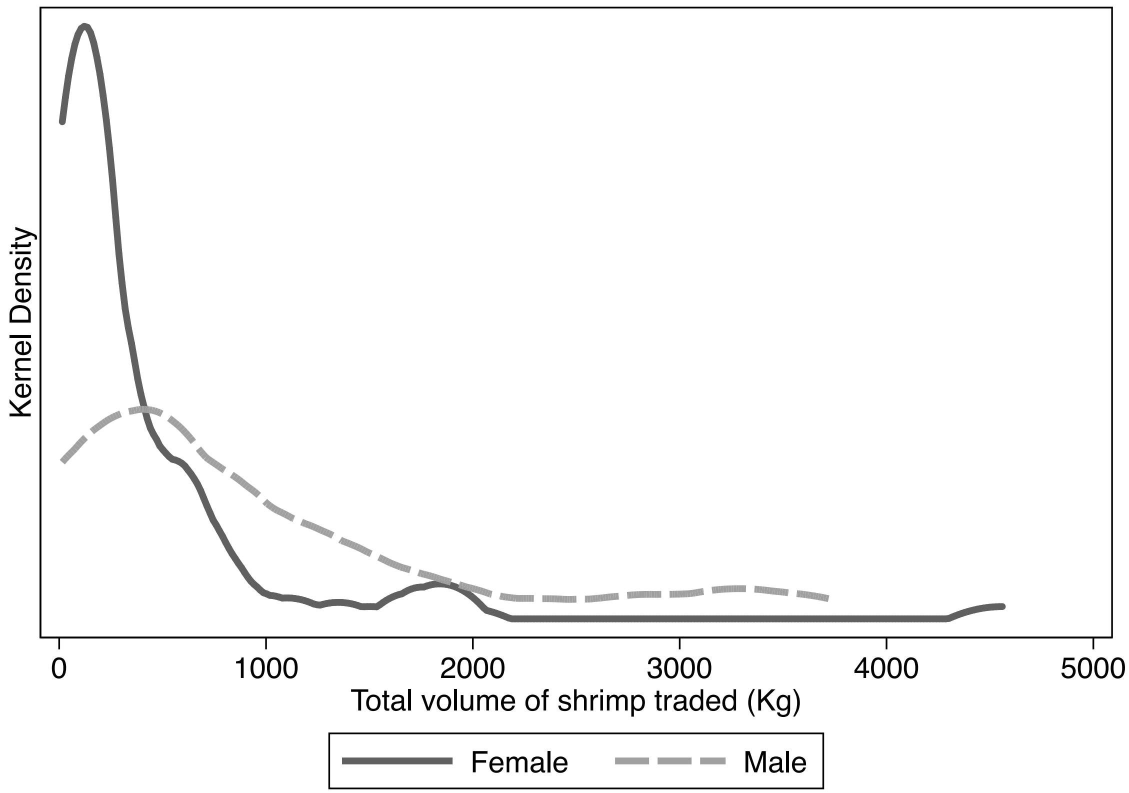

Figure 6: Distribution of trading costs per kilogram

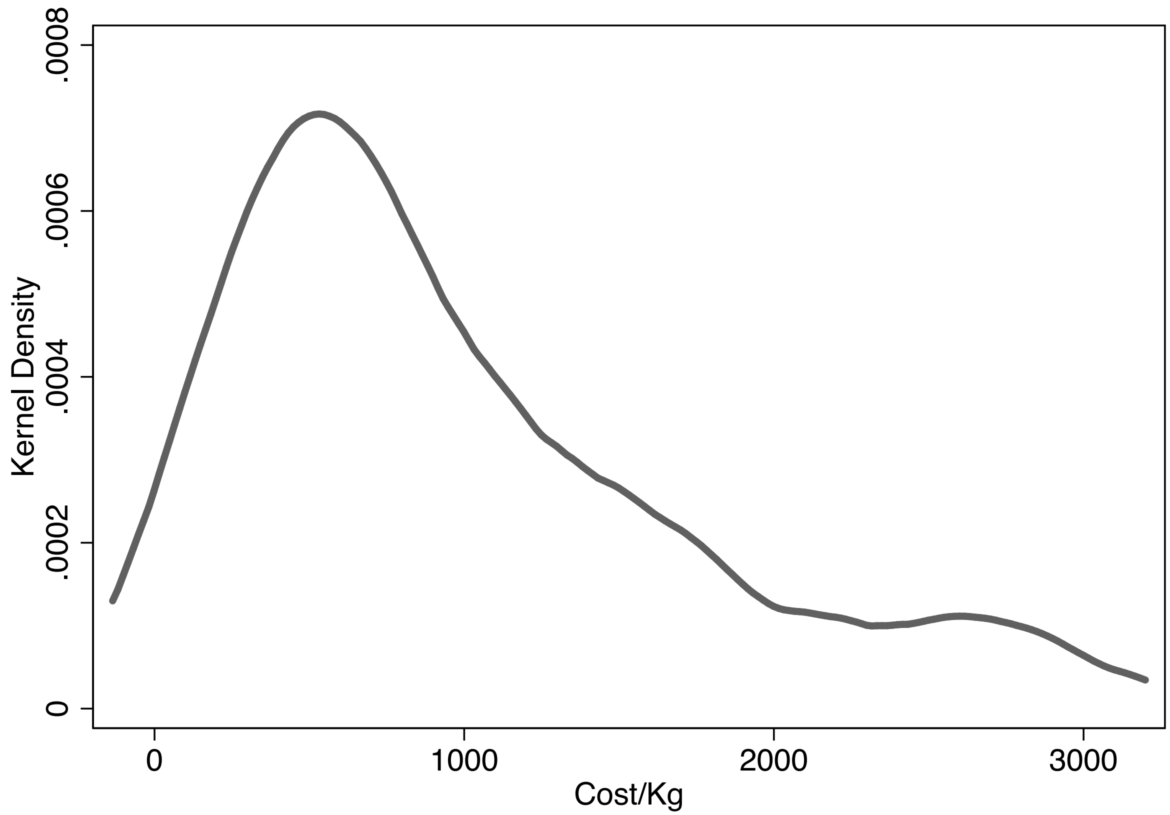

Table 23: Stochastic Cost Frontier Analysis Results

	VARIABLES	(1) Cost	(2) Cost/ Kg	(3) Cost	(4) Cost/ Kg
COST	Total quantity traded (Kg)	0.78**	-0.22**	0.79**	-0.21*
		(0.071)	(0.071)	(0.085)	(0.085)
	Price of one casual labor day (1000 IDR/Day)	0.28	0.28	0.24	0.24
		(0.178)	(0.178)	(0.169)	(0.169)
	Distance to shrimp production area (Km)	0.34**	0.34**	0.35**	0.35**
		(0.057)	(0.057)	(0.056)	(0.056)
	Transportation capital of firm (Index)	-0.15	-0.15	-0.00	-0.00
		(0.145)	(0.145)	(0.149)	(0.149)
	Area of trading depot (ha)	0.17+	0.17+	0.13	0.13
		(0.095)	(0.095)	(0.091)	(0.091)
	Productive capital endowment (Index)	0.11	0.11	-0.06	-0.06
		(0.164)	(0.164)	(0.172)	(0.172)
	District==Rembang	0.14	0.14	0.21	0.21
		(0.162)	(0.162)	(0.158)	(0.158)
	District==Bulukumba	0.55*	0.55*	0.82**	0.82**
		(0.259)	(0.259)	(0.226)	(0.226)
	District==Barru	0.52*	0.52*	0.80**	0.80**
		(0.206)	(0.206)	(0.179)	(0.179)
	Constant	0.02	0.02	-0.04	-0.04
		(0.678)	(0.678)	(0.703)	(0.703)
$ln(\sigma^2_V)$		-1.52**	-1.52**	-1.63**	-1.63**
		(0.346)	(0.346)	(0.335)	(0.335)
$ln(\sigma^2_U)$	Total quantity traded (Kg)			-0.31+	-0.31+
				(0.177)	(0.177)
	Upstream contract (binary)			1.03**	1.03**
				(0.299)	(0.299)
	Downstream contract (binary)			-1.05*	-1.05*
				(0.496)	(0.496)
	Specialized in one variety only (binary)			-0.61+	-0.61+
				(0.362)	(0.362)
	Social capital downstream (binary)			-0.80*	-0.80*
				(0.348)	(0.348)
	Trader gender is female (binary)			0.18	0.18
				(0.320)	(0.320)
	Education of the trader (years)			-0.10*	-0.10*
				(0.039)	(0.039)
	Constant	0.55**	0.55**	3.45**	3.45**
		(0.200)	(0.200)	(1.257)	(1.257)
	Observations	188	188	187	187

Standard errors in parentheses
** p<0.01, * p<0.05, + p<0.1

Table 24: Truncated regression results (DEA inefficiency)

VARIABLES	(1) Cost	(2) Cost/Kg
Total quantity traded (Kg)	-0.09*	-0.01
	(0.190)	(0.025)
Upstream contract (binary)	0.09*	0.04*
	(0.046)	(0.021)
Downstream contract (binary)	-0.24**	-0.07*
	(0.065)	(0.031)
Specialized in one variety only (binary)	-0.10+	-0.04+
	(0.021)	(0.024)
Trader is related to a downstream agent (binary)	0.07	0.01
	(0.046)	(0.020)
Trader gender is female (binary)	0.03	0.02
	(0.047)	(0.022)
Education of the trader (years)	-0.02**	-0.01*
	(0.008)	(0.003)
Constant	1.33**	0.912**
	(0.190)	(0.087)

Standard errors in parentheses
** p<0.01, * p<0.05, + p<0.1

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