Risk Management in Gathering Economies

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Final version received November 2005

ABSTRACT This article extends the literature on the interplay of environmental risk and welfare into the setting of coastal fisheries gathering. It reviews the sources of covariate and idiosyncratic production risk creating income shocks to gatherers and discusses the institutions that best mediate shocks across different settings. We rely upon a principal-agent framework between larva-gathering agents employed by boat-owning principals who supply seed to shrimp farms. Two datasets from a Central American fishery are used to test the hypotheses concerning contractual performance across environments. Which contract provides the highest mean income (and variation) depends upon the underlying production catch data. In the farm production records dataset with strong catch trends, a simplified relative payments contract would perform better in reducing income risk in locations of stronger covariate shocks, but at the price of significantly lower mean earnings for gatherers. In areas of idiosyncratic shocks, such as localised water pollution, piece-rate contracts would perform better. Objective risk exposure to gatherers was lower under relative payments, supporting the hypotheses. Actual results in the Honduran case were conditioned by imperfect labour markets and the substitutability of hatchery larva.

I. Introduction

The gathering of fishery, forest and mineral products can provide a steady source of foreign exchange earnings and employment generation in many countries. Sustainable natural resource gathering has been heralded by many as an ideal means to combine environmental preservation with poverty reduction (May et al., 1985; Hecht and Schwartzmann, 1988; Fearnside, 1989; Peters et al., 1989; Allegretti, 1990). Many of these studies have demonstrated high benefit-cost ratios and returns to labour as compared to agriculture. Gathering could also be a risk-reduction activity by providing a natural insurance against variation of other incomes (Pattanayak and Sills, 2001).

Thus far economic analysis has given little attention to how extractive incomes vary over time or natural events, as compared to traditional activities. Environmental conditions ranging from rainfall patterns to soil types and water quality affect yields, so households involved in gathering face both shared covariate and individual...
idiosyncratic shocks to their revenue streams. Rainfall patterns and regional pollution are important common shocks affecting the seasonality, density and species composition of the products collected. In semi-arid land settings herders often face covariate drought risks as well as local rainfall variation (Nugent and Sanchez, 1998; Smith et al., 2001; McCarthy and Vanderlinden, 2004), while in tropical forests covariate flood shocks and idiosyncratic health shocks have been identified (Takasaki et al., 2004). In the wetland setting of this study, fish seed gatherers face covariate water salinity shocks as well as estuary-based water quality and fish habitat-localised shocks.

Various ex-ante and ex-post strategies (diversification, insurance, borrowing and asset liquidation) are available to manage risk, but not all options are available in all settings. Gathering households often lack agricultural land access, so crop diversification, field scattering, asset sales and other ‘conditional self-insurance strategies’ are unavailable.¹ Diversification of labour time and forms of reciprocity are the more feasible risk management devices. Different contracts and institutions also mediate risk between gatherers and buyers. Share contracts – which divide risk and reduce moral hazard – have been used in fishing, mining and other extractive systems (Sutinen, 1979; Nabli and Nugent, 1989; Platteau and Nugent, 1992). But it is not clear whether this is the optimal contract across a wide variety of environmental settings. Some recent literature demonstrates institutional adaptation to income risk from environmental conditions as an extension of the economic theory of property rights (McCloskey, 1976; Bromley and Chavas, 1989; Thompson and Wilson, 1994; Nugent and Sanchez, 1998).

Our analysis here extends that literature to a wetland gathering setting by reviewing hypotheses concerning the optimal institutions across environmental settings, then testing the contractual welfare outcomes using two datasets. It uses a semi-historical case study of larva gathering, an interesting fishery relevant to the emergent, booming aquaculture industry in developing countries. Aquaculture seeds are an important non-timber product extracted from mangrove estuaries, and close to a quarter of a million gatherers undertake larva collection worldwide.² The paper addresses the interplay of contracts and environmentally-generated risk by testing Nalebuff and Stiglitz’s (1983) theoretical results concerning the optimality of relative performance systems and piece rates under specific conditions. It provides guidance to managers, donors and policy-makers concerning the links between institutional choice and poverty reduction and methods to broaden the developmental impacts of natural-resource based industries.

The organisation of the paper is as follows. Section II summarises theoretical models of risk management that can be applied to an extractive economy. The analysis concentrates on the risk borne by gatherers as agents, with some reference to that borne by boat owners (boat owners as principals). Section III describes the research setting and two datasets used to analyse the Honduran larva-gathering case. It first discusses likely sources of covariate and idiosyncratic risk affecting larva fish availability in different zones. Then data on gathering household activities and incomes is compared across contractual regimes. The household data demonstrate generally higher welfare outcomes for gatherers paid fixed wages with incentives (relative payments). In contrast, the outcomes across different contracts extrapolated from the purchasing data of seven farms suggests that traditional piece-rate schemes

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could provide higher mean incomes and higher poverty reduction in the region of highest idiosyncratic risk. Yet it is clear the boat owners profit more frequently when paying gatherers under relative payments, partially explaining their widespread usage and outcomes in the actual village data. The discrepancies between the actual household data and extrapolated farm results also derive from a redistributive species bonus scheme linked to the relative payments scheme at that time. Finally in Section IV lessons about how environmental factors can affect risk trends and contractual choice in similar fisheries are discussed.

II. A Theoretical Framework for Gathering and the Importance of Risk Management

Production Environment of Aquaculture and Larva Seed

The benefits and costs of the globalisation and maturation of the international shrimp aquaculture industry are well documented (e.g. Bailey, 1988; Clay, 1997). Globally, mariculture involves a significant transformation of an estuarine raw material (larva seed) into a high-valued export product (jumbo shrimp) through the dynamics of pond grow-out systems and stringent processing techniques. Less studied are the changing patterns of input provision and backward linkages of the industry. These supply industries represent a large source of indirect job creation and one of the industry’s sources of potential poverty reduction.

The history of market structure and industrial organisation in the larva fishery product market has not been widely studied; however, the influence of Asian managers and global technicians in the transferring of production strategies and contractual innovations to Latin America is well-known (Rosenberry, 2004). Exploring the nature of derived demand (Yeung, 1972) and the basic characteristics of the raw material can illuminate features of its industrial organisation (Barham et al., 1994). The organisation of larva seed gathering is primarily influenced by the sequencing problem facing the vertically coordinated aquaculture industry. Farm-raised products for an export market must meet timing and quality standards which ultimately feed back to the derived demand for larva seed (Figure 1). Aquaculture farm managers often try to harvest products twice a year to meet ‘market windows’ of high prices; working backwards, this implies stocking aquaculture ponds with seed several months previously. Many aquaculture farms demand wild seed from boat owners but still turn to expensive laboratory seed from hatcheries if natural shortages create an inadequate supply.

Absolute natural seed supply is set by the interaction of human behaviour, sunk cost considerations and the natural environment. Only some suppliers will undertake the specialised investments in larva transport; from this a moderately-upward sloping-supply curve is likely as boat owners and gatherers search across sites of different gradation. Other studies have documented that a large number of boat owners sell wild seed in a moderately competitive product market, with high supply elasticity within temporal windows of availability. In the case study below the export and import of larva seed was negligible, with this trend to eliminate market shortages and surpluses more common in Asia (Sadovy and Lau, 2002). The availability of a synthetic substitute (hatchery larva) also affects its relative scarcity; in the mid-1990s the ‘weaker’ synthetic product was seen as an imperfect substitute
for the wild seed. Shrimp farm managers interviewed in the case study commented that wild larva price trends \((P_g)\) often confront a ceiling set by the value of imported hatchery seed and that the boat owners’ operating costs provided a formula for a minimum price floor.

There are two stages of contracting (and potential principal-agent relationships) between parties in Figure 1 for the wild larva provision. First, farm managers contract with boat owners to procure the larva input. Then the boat owners act as labour recruiters to contract the effort of the gatherers/fisherpeople. But similar to the reality of international agribusiness concerns such as poultry broiler production (Knoeber, 1989), the perishability of live larva has forced the contracting parties to locate near each other and created site-specificity and relation-specific assets. This means boat owners can feasibly sell only to farms within one hour of the gathering site, and geographic concentration means a probable locational oligopsony exists among the shrimp farms as seed buyers.

Initially shrimp farms in most of Latin America relied primarily upon wild seed to stock ponds; farms purchased seed on a spot market of boat owners who delivered the product of individual gatherers or teams. But uncertainties about the frequency of natural supplies, particularly the desired Pacific white shrimp \((P. Vannamei)\), and debates about farm-gate pricing across species lead to changing procurement strategies. By the early 1990s many farms received seed from the three sources in Figure 1: (1) a fixed group of boat owners/labour recruiters contracted verbally to deliver larva on specified dates with set price differentials by species and incentive rules; (2) a spot market of boat owners (with gathering crew) paid on a piece-rate basis; and (3) an emerging national and international hatchery sector to fill natural shortages. By the year 2000 hatcheries – some vertically-integrated with the farm
units—supplied the largest proportion of larva since emerging disease threats necessitated greater quality control. However, many emerging aquaculture-producing nations of South Asia and Africa still rely on wild larva input procurement strategies which dominated Latin America in the mid-1990s.

Our datasets focus on the partial-equilibrium relationship between boat owners (labour recruiters/principals) and gatherers (agents) in the bottom half of Figure 1. Moral hazard and risk shifting are the defining factors. Unlike other fishery and forest products, common property externalities are not a pressing concern. Gatherers usually work in isolated and unsupervisable settings, and natural shocks affect production outcomes. Boat-equipment owners want labourers at the lowest cost but also need a large quantity of extracted product to resell to the shrimp farms and receive a return on asset investments. Following Nalebuff and Stiglitz (1983), the product 'q' of each agent 'i' stems from human effort and the natural environment:

\[ q_i = f(e_i, \theta, \eta_i) \]  

where \( i \) = agent, \( \eta_i \) = idiosyncratic stochastic noise into gathered product output \( \eta \sim N(\mu_\eta, \sigma^2) \), \( \theta = \) common shock into gathered product output \( \theta \sim N(\mu_\theta, \sigma^2) \) and \( e_i = \) a continuous variable representing i’s gathering effort during a work period.

Gathering is probabilistically related to the unobserved effort and environment; effort enhances the catch, but at a decreasing rate: \( f_e > 0, f_{ee} < 0 \).

Environmental factors are unpredictable and serve as sources of covariate and idiosyncratic normally-distributed shocks (\( \theta \) and \( \eta \) respectively). The abundance of larva is tied to seasonal factors, with large quantities expected in the rainy season and the high tides of a new or full moon (Duron, 1995). Besides the lunar cycle, water salinity is perhaps the most important covariate factor affecting production. Overall larva (and specific species) abundance and water salinity are inversely correlated, and shrimp larvae prefer moderate salinity of 15–20 parts per thousand (ppt) (Duron, 1995; Kapetsky et al., 1987). Rainfall abnormalities are covariate shocks as salinity levels rise during drought periods, and rainfall influences water temperatures, water turbidity and the level of dissolvable oxygen (Torres and Wong, 1983).

Idiosyncratic shocks related to specific gathering sites and a gatherer’s personal knowledge also determine the total larva quantity available for capture across time. Samarakoon and Raphael (1975) identify the soft quality of an estuary surface bottom and the availability of alimentation as localised factors attracting larva. Farm management practices around water quality and mangrove cover impact wild larva abundance in a localised fashion at specific periods. High levels of water pollution and loadings lower dissolvable oxygen levels in the estuaries, and mangrove deforestation reduces the food source of shrimp larva and other fish species, with the result magnified particularly during the dry season (Kapetsky et al., 1987; Turner, 1989; Parks and Bonifaz, 1994; Duron, 1995).

Behavioural Assumptions

1. Agents. Agents make decisions about how to spend their time across many activities, including agricultural wage labour and natural-resource gathering. Although effort provides disutility it creates extracted products (q) which are
exchanged for utility-providing income \((y)\) through contractual arrangements. The utility function equations are:

\[
U_i = U(\mu_i, \sigma_i, \epsilon), \quad U_\mu > 0, \quad U_\sigma < 0, \quad U_\epsilon < 0
\]  

(2)

Following Rosenzweig andBinswanger (1993) household allocation of productive assets can be extended to consider the allocation of labour time, with the gathering activity \(g\) as one of many \(j\) activities. Assuming a linear homogenous income function in the inputs, the average return and standard deviation of the total income of \(j\) activities is given by:

\[
\mu = E(Y) = \Sigma_j (z_j E(Y_j))
\]

\[
\sigma = (V(Y))^{1/2} = (\Sigma_j z_j^2 V(Y_j) + \Sigma_j \Sigma_k z_j z_k \text{cov}(Y_j Y_k))^{1/2}
\]

(3)

where \(z_j\) is the share of resources devoted to activity \(j\); \(z_j < 1\); and \(\mu\) and \(\sigma\) are mean and standard deviation of income across all activities.

Here households determine their allocation of labour time based on the expected returns of the activity, where the utility of expected returns must achieve that of an alternative time use (such as a going wage \(Y_o\)). Households rank the attractiveness of an activity, so that labour supply is endogenous with the history of activity returns. Equation (3) also demonstrates diversification into some activities (such as gathering) could lower the overall variance of household income if their returns covary negatively with other earnings and the returns are not perfectly correlated.

With risk aversion, households need higher mean income \(E(Y)\) levels to accept higher risk levels in the standard deviation of earnings, \(\sigma(Y)\). We assume that poor gathering households possess some degree of risk aversion and would prefer a safe income over a stochastic income with the same mean value. Ranking the extent of income spread from different activities or contracts often turns on finding which has the lowest coefficient of variation. Alternatively, to assess the risk-shifting effects of different contracts for a single activity, several recent agricultural studies have tested the hypothesis of equal payment variances or examined the ratio of standard deviations of the contract returns (Knoeber and Thurman, 1995; Martin, 1997).

But it is also common to determine the level of objective risk exposure brought on by an activity choice. The objective risk exposure of households specialising in gathering may be large if there is a high probability that earnings from gathering will fall below a predetermined safety net. Earnings below the safety net imply households will have to tap into other assets to avoid starvation; thus these activities will be ranked lower. Concern about downside risk is commonly modelled as a safety-first rule in overall peasant decision-making. Following Roumasset (1976), a household chooses to minimise the probability that random income \(r\) across different activities (or gathering contracts ‘\(g\)’) falls below a disaster level \(d\):

\[
\text{Min} \alpha = \text{Pr}(r_g \leq d)
\]

(4)

where \(\alpha\) is the accepted disaster probability (Bigman, 1996). Studies of food security commonly assess the probability that a given activity will make cereal or income availability fall below a minimum level (i.e. \(r_g \leq d\)), ranking the high probability outcomes lower.
Alternatively, ranking of the earnings potential of different contracts can be examined in an expected utility framework, under various assumptions including a normal distribution of returns. We consider individuals with either constant (CARA) or decreasing (DARA) absolute risk aversion. CARA (no income effects in an individual’s attitudes towards risk) in the utility function allows us to work with the popular exponential utility function, \( U(y) = -e^{-Ay} \), with \( A \) as the risk aversion parameter. A cardinal ranking of outcomes can be calculated from the following mean-variance equation (Freund, 1956):

\[
\text{EU}_g = \mu(y_g) - 0.5\sigma^2(y_g)
\]

Alternatively, the cost of risk can be described using a constant relative risk aversion (CRRA) parameter \( R \) depending on the mean income level, with values commonly falling between 0.3 and 1.7 (Binswanger, 1980). The utility function with CRRA, \( U(y) = y^{1-r}/(1-r) \), can be simplified by considering the case of relative risk aversion = 1, which becomes the natural log function \( U(y) = \ln(y) \); this function exhibits DARA properties useful for developing country settings in which poorer families may express aversion to downside risk. By a Taylor expansion (Anderson et al., 1976), this function can be reduced to a mean-variance equation dependent on wealth \( w \) levels:

\[
\text{EU}_g = \ln\left[ w_0 + \mu(y) \right] - \left\{ (0.5 \sigma^2(y))/(w_0 + \mu(y)^2) \right\}
\]

In the empirical analysis of risk exposure below, we choose a wide range of absolute risk aversion ‘\( A \)’ values between 0.005 to 0.5 in (5) which correspond to a constant relative risk aversion parameter between 0.3 and 1.7 at the sample mean income level, and we vary the initial household wealth from 0 to 200 lempiras ($0–$37) in (6). We also compare the probability that incomes fall below a disaster level in (4).

2. Principal. We assume principals are profit-maximising price takers operating in an imperfectly competitive product market described above. As one of many sellers, we assume the principal (boat owner) maximises his profit by maximising the difference between total revenue from seed sales (\( P_gQ_g \)) less the operating and maintenance costs (\( C \)) of larva fishing. The boat owner must ensure that the expected utility benefits derived from gathering (\( EU(Y_g) \)) are at least as great as that offered from other activities \( o (U(Y_o)) \) to ensure the agent’s participation. In the case study below most boat owners were wealthy members of the gathering villages and diversified their income streams across gathering, cattle ranching, commerce and fishing other species. So assuming risk-neutrality, the principal’s problem is:

\[
\max \pi = P_gQ_g - Y_g - C \quad \text{s.t.} \quad EU(y_g(\mu, \sigma), e_g) \geq U(Y_o)
\]

Imperfect competition characterises the rural labour markets (between principals and agents) in many gathering settings. Credit constraints limiting equipment accumulation by agent labourers, and geographical travel barriers, may limit worker self-selection across contracts. Positive or zero economic profits for principals (as labour buyers) are both possible outcomes.
Incentive Compatible Contract Design

Transaction costs considerations (Williamson, 1979) also factor into the relationships, leading to a reliance on wild-seed provision in the case study below. Vertical integration of the industry (with shrimp farm managers using their own employees to gather or produce hatchery seed) did not occur at the time of the case study since the contracting environment was only moderately complex during this period. Instead, a number of boat owners worked under an exclusive contract to shrimp farms to supply larva as needed at a predetermined price by species; farm managers often provided low-cost equipment loans or resales to the boat owners in exchange for loyal work and sales on-call. Some of this equipment (such as oxygen tanks) represents specialised investments not useful for other work, implying costly bargaining and the need for contracts. Although these contracts helped secure farm seed supplies, managers also purchased larva on a ‘spot market’ from a second group of boat owners to meet input procurement demands. The first group of boat owners/labour recruiters operated in a principal-agent relationship with their gatherers by offering relative performance incentives in the labour contract, while the second group of boat owners handled moral hazard through piece rates. We next turn to this bottom level of Figure 1.

(1) Relative Performance Contracts. In a relative payment system, agents’ compensation is based on performance compared to other players. Best performers receive a prize while worst-performing agents are penalised or receive a smaller prize. In one strand of the tournament literature, placement is done by ordinal ranking while other models focus on linear relative performance schemes in which a cardinal measure (say a group mean) is used to compare an agent’s performance (Lazear and Rosen, 1981; Holmstrom, 1982; Nalebuff and Stiglitz, 1983). The case study contract for larva collection relies on a linear relative performance measure in which a gatherer’s product is compared to some proportion of the mean of all boats (and gatherers) consistent with Theorems 3 and 8 in Holmstrom (1982). This assumes all gatherers within a boat work as a team rather than engage in free-riding behaviour.

Specifically, farm managers examine the larva quantity delivered from all the boats so a clear ranking of the best- and worst-performing boats emerges. The worst-performing boats (say those well below the mean in a daily or weekly ranking) were not invited to deliver product in the subsequent period; this meant both the boat owner would change the crew and ‘fire’ the previous larva gatherers. For gatherers forced to then work in agricultural labour, this firing penalty is equivalent to a low opportunity wage, so individual incentives derive from the team/boat performance. Since the boat owner’s welfare is affected by the gatherers’ effort, these owners used catch and species information (provided by the shrimp farm managers) to provide gatherers the incentive wage packages described below; additional incentive devices (such as kinship ties between boat owners and gatherers) are not outlined here.

In this relative payments system (labelled superscript RP), the agent’s earnings $y$ can be described in a one-period framework in which the probability $\psi$ of receiving a high prize $B_H$ depends on the agent’s effort and relative performance. A straight linear relative performance scale is considered, in which the agent’s (i.e boat’s) output must be greater than (some proportion $k$) of the overall mean $\bar{q}$ to receive a high prize ($\psi = 1$). If poor performance is observed, the agent receives a penalty or low wage prize $B_L$.\[y = \begin{cases} \end{cases} \]
Assuming each crew member is an identical agent, the agent’s income becomes:

\[ Y^{RP} = \psi B_H + (1 - \psi)B_L \]  

\[ \psi = \psi(q_i \geq k \{q\}) \quad \psi = 1 \quad \text{if } q_i \geq k \{q\} \]

\[ \psi = 0 \quad \text{if } q_i < k \{q\} \quad 0 < k \leq 1 \]

The tournament literature demonstrates that based on (1), (2) and (8) agents chose effort such that the marginal probability of being above the mean just equals the marginal disutility of such work, considering the effects of stochastic parameters (Nalebuff and Stiglitz, 1983).

The prize packages \( B_L \) and \( B_H \) are normally assumed to be fixed parameters so that the source of income variation derives only from the effort and shock distributions of the reward probability \( \psi \). In the classic Holmstrom model the prize/penalty rule is based on an agent’s output measured against a weighted average of peer performance, but determining the appropriate weighting \( k \) depends on the precision of the idiosyncratic error terms (Holmstrom, 1982). Thus it is common to simplify the model into a linear relative payment scheme (described in Appendix 1) in which the scale of the agent’s output against the group mean determines compensation (Martin, 1997).

A prize package could involve additional variation. Adding a share component \( (c) \) to a relative payments package could introduce income swings beyond that driven by the prize probability \( (\psi) \), with low-performing workers even possibly earning a high income through a lucky share bonus. In the case study (and data extrapolations) below, a redistributive bonus occurred based on the appearance of a prized larva species (captured by chance, not effort), and this bonus is added only to the prize package \( B_H \). In this case the wage package becomes:

\[ Y^{RP} = \psi (B_H + \{c q_i, \omega\}) + (1 - \psi)B_L \]  

\[ \psi = \psi(q_i \geq k \{q\}) \quad \psi = 1 \quad \text{if } q_i \geq k \{q\} \]

\[ \psi = 0 \quad \text{if } q_i < k \{q\} \quad 0 < c, \omega \leq 1 \]

with \( c \) = a redistributive share parameter; \( \omega \) = the proportion of the target species of the gathered product.

(2) **Piece-rate/Share Contracts.** Piece-rate contracts also make sense for larva gathering. In the piece-rate system, a boat and an agent’s earnings are tied to the gatherers’ effort, the state of the natural environment and the per unit compensation level. For each identical agent within the boat, compensation depends largely on an agent’s absolute performance and the ‘performance’ of the natural environment. In the piece-rate system (with superscript PR), the agent’s earnings each period are given by the total product gathered multiplied by the pre-determined piece-rate \( a \). The equation is:

\[ Y^{PR} = a q_i (e_i, \theta, \eta_i) \]
Appendix 1 shows that in the linear relative payment scheme simplification of (8) income variation is smaller under a relative payments than under piece rates (10) when a large covariate shock is present. Nalebuff and Stiglitz (1983) also formally explore how the natural environment ($\theta$, $\eta$, in this case) impacts the efficiency of different contractual forms for risk-averse agents. Ultimately contract efficiency affects gatherer welfare, decisions to continue the activity, and endogenous labour allocation as described in (3). Nalebuff and Stiglitz initially analyze contests based on ordinal rank, yet suggest similar results for cardinal schemes using relative performance. They find:

(a) Agents should prefer competitive compensation/relative payment schemes over piece rates when the risk from a common environmental variable is large ($\sigma^2_\theta > \sigma^2_\eta$). This is because relative performance contracts eliminate the covariate shock from an agent’s payment. A contest scheme truncates the extreme outcomes which risk-averse players dislike. Yet volatile environmental variables may reduce the incentives of piece-rate workers. In areas of relatively high idiosyncratic risk ($\sigma^2_\theta > \sigma^2_\eta$) piece-rate contracts would enhance agent welfare.

(b) Competitive compensation schemes become more optimal in raising utility and effort, as the number of contestants grows. As player numbers increase, there is more and better information available about the true state of the environment and effort levels. Holmstrom (1982) shows that with a large number of agents, the average output of all agents more closely reflects the mean interplay of effort and the natural environment. For gathering, a larger number of boats from which the farm manager could determine the mean output and ranking would increase the efficiency of relative payment schemes. Although the number of boats may be fixed at the beginning of a production cycle and ranking period, over time the number may change as gatherers consider the expected utility of gathering against its alternatives.

The Nalebuff-Stiglitz results are based upon agents with a quadratic utility function (increasing absolute risk aversion) and the simplification of a production function multiplicative in the covariate shock and linear in the idiosyncratic shock. Whether the results hold for a wider range of risk preferences and production settings has implications for the usefulness of development theory in practice. Data from a coastal setting (southern Honduras) are used to examine these predicted trends in gathering earnings. ANOVA analysis determines whether covariate or idiosyncratic factors dominate in each of the observed locations which have differential environmental disturbances. Whether these actual contracts are ‘optimal’ as predicted by Nalebuff-Stiglitz is answered using datasets from a household village survey and farm larva purchase records. The first theoretical result is tested by establishing whether relative payments provide higher welfare in zones of high covariate risk. Risk-averse agents would prefer a contract with a lower overall coefficient of variation, a lower probability of disaster and higher expected utility, as described in equations (4)–(6). The second theoretical result is seen when increasing the number of boats per farm changes outcomes across contracts and locations.
III. Honduran Research Industry, Setting and Methods

In the mid-1990s farm-raised shrimp production was Honduras’ third largest export, and larva fry gathering represented the single most important form of industry employment. Some 1,500 larva gatherers worked throughout the Gulf of Fonseca by pushing a dense hoop net along the edge of an estuary during low tide; small shrimp larva were collected in the net and passed by hand into collection buckets and tanks.

Three sites in southern Honduras were purposely selected to consider variation in gathering incomes in the mid-1990s across different production environments. First, weekly household data on 105 larva-gathering families in three villages were collected in 1993–94. Variables such as weekly gathering production quantities and incomes were measured, as well as other sources of household income and background characteristics. The weekly observations are aggregated to monthly and yearly statistics. The second dataset includes 4,228 larva purchase records given by six farms in the three zones in 1993. The purchase records show larva catch outcomes of approximately 60 boat owners and, indirectly, 250 gatherers. The data represent a relatively ‘clean’ period before the onset of natural disasters (e.g. Hurricane Mitch in 1998).

Production Risk and Contractual Relations in Honduran Larva Gathering

1. Production and Environmental Variation. The study sites bordering the Gulf of Fonseca range from a southernmost area near the Nicaraguan border to areas near the Salvadoran border. In the San Bernardo sub-zone (Zone 1) about a dozen large mariculture enterprises control nearly 94 per cent of the wetlands. Resident fishermen and larva gatherers use boats to reach estuaries and the open sea there. Biologists often report that the San Bernardo Zone has (i) wider variation in water salinity and temperature variation and (ii) higher levels of P. Vannamei (and higher intra-month variation of Vannamei) due to the area’s proximity to Nicaraguan waters. This suggests Zone 1 could be the area of highest covariate risks. On the other hand, this zone is the most developed with problematic shrimp farm water use and effluents, as well as numerous upstream water pollution factors.

The drier Laure/Monjaras region (Zone 2) is home to four large farms and some 30 small farms. Good larva-gathering sites are accessible by foot across old salt flats and boats to the mangroves. Aerial photographs suggest mangrove deforestation and the destruction of larva habitat generally appears the greatest around the Monjaras area of Zone 2 (Stanley and Alduvin, 2002). This could create large localised idiosyncratic shocks to gathering since fish habitat has been destroyed. The Chismuyo sub-region (Zone 3) on the Salvadoran side of the Gulf of Fonseca is a desert-like highly salinated zone in which primarily small family farms operate. Three neighbouring estuaries are accessible by boat and on foot. There is little deforestation and water pollution in the zone, so covariate and idiosyncratic risks are expected to be lower.

ANOVA analysis of larva production trends can assist in verifying differential risk across production zones. The quantity of larva captured is an initial (although noisy) proxy for the covariate shock parameter. Seasonality, the lunar cycle, natural trends in water salinity and temperature and human effort all affect quantity. The species
composition is perhaps a better proxy since gatherers have no control over this trend, and the composition of *P. Vannamei* is directly related to salinity levels. The ANOVA analysis asks whether the variance in quantity and species captured (and *Vannamei* species composition) associated with a specific, covariate, factor is larger than the variance associated with random, idiosyncratic disturbances. Here a seasonal dummy variable (as a proxy for the rainy or dry season) and a lunar cycle dummy variable (to distinguish the period following a full moon and last quarter from the new moon weeks) are the independent regression variables and covariate factors affecting all production zones simultaneously. These capture a general upward trend across the months as well as intra-month spikes around the lunar cycle. A larger F-ratio (as the ratio of the residual sum of squares over the error sum of squares\(^{13}\)) suggests the covariate factor may be significant in explaining the total variation; the R\(^2\) from a regression of the independent season and lunar variables on yields explains what percentage of the total variation is attributable to the covariate factors. Production variances not explained by the covariate effect (residuals) are related largely to gatherer effort and idiosyncratic factors of a given estuary (such as localised water pollution). Here we focus on differences in yields across boats as a signal of the importance of gatherer effort and the gathering site. The R\(^2\) from a regression of boat dummy variables on yields explains what percent of the total variation is associated with this component of the overall idiosyncratic trend.

The large F-statistics in Table 1 mean that both the covariate and idiosyncratic factors are statistically significant in explaining yield variation in most cases. However, important differences in the relative weight of these factors emerge in the R\(^2\) values across the three zones. In Zone 1 the large number of boats suggested a farm-by-farm analysis of the relative shocks. Mixed results appear; for the largest farm the seasonal and lunar cycle effects explain 17 per cent of the yield variation while boat differences account for only 2 per cent. The relative importance of the two factors is nearly equal for the other farms; however, species percentage differentials are better explained by the covariate shock on all three farms. In Zone 3 the importance of the covariate shock is clear, accounting for 15 per cent of the catch variation there. Additionally, testing the restriction that boat ‘idiosyncratic’ effects were zero was accepted.\(^{14}\) Following the logic of Nalebuff-Stiglitz, this means relative payments would be the most efficient contract to optimise gatherer welfare in Zones 1 and 3 since covariate risk is relatively more important than idiosyncratic shocks there.

A different trend emerges in Zone 2. Here the difference across boats (as an idiosyncratic factor) is more important than the shared seasonal and lunar factors. Inter-boat differentials explain 29 per cent of the catch variation and 16 per cent of the yield variation. A similar pattern emerges in the factors underlying species variation. This suggests piece rate payments could provide a higher welfare for gatherers in Zone 2.

Another interesting result concerns the number of boats hired by each farm in the production data. Zone 1 and 3 farms tended to work with a greater number of boat owners than those in Zone 2. The second Nalebuff-Stiglitz hypothesis implies a relative payments arrangement may be less successful in promoting incentives in Zone 2 since fewer participants there provide less accurate information about yield trends.
Table 1. Larva trends across production zones (daily purchase data from 6 shrimp farms)

<table>
<thead>
<tr>
<th>Zone 1</th>
<th>ANOVA F-statistic, R²</th>
<th>ANOVA F-statistic, R²</th>
<th>ANOVA F-statistic R²</th>
<th>ANOVA F-statistic, R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>of capture by season, lunar cycle Covariate</td>
<td>Idiosyncratic</td>
<td>of capture by contractor</td>
<td>Idiosyncratic</td>
</tr>
<tr>
<td>SHOCK:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All farms</td>
<td>42.6**; 0.05</td>
<td></td>
<td>64.89**; 0.07</td>
<td></td>
</tr>
<tr>
<td>Farm 1 (GM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm 2 (AF)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm 3 (CM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Optimal contract’: relative payments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 2</td>
<td>15.02**; 0.06</td>
<td>19.28**; 0.29</td>
<td>23.85**; 0.10</td>
<td>9.25**; 0.16</td>
</tr>
<tr>
<td>All farms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm 1 (CL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm 2 (A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Optimal contract’: piece rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone 3</td>
<td>88.59**; 0.15</td>
<td>1.6; 0.01</td>
<td>43.84**; 0.08</td>
<td>6.73**; 0.06</td>
</tr>
<tr>
<td>Farm 1 (LB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: **signifies statistically significant at 95% confidence level, *signifies 90%.
2. Observed Contractual Regimes. Gathering payment variation in recent Honduran history matched that suggested by contractual choice theory. The large-scale shrimp farms in the San Bernardo Zone 1 implemented a system of ‘retained boat owners’. These boat owners then offered a fixed-wage relative payment (RP) incentive system for gatherers. Fired workers had a hard time obtaining another relative-payment contract and generally remained in traditional agricultural activities at the going wage (approximately 10 lps or $1.82 at the time, based on income data from three control villages in the study). The wage package to a good worker (equation (9)) consisted of a fixed daily wage (17 lps, or $3.09) with a species bonus of about 0.22 lps/1,000 of the targeted *P. Vannamei* species if the boat owner earned a profit. In other words, the actual relative payment income is:

\[
W_{RPi} = \begin{cases} 
17 + (0.22 Q_t P. Vannamei \text{ species}) & \text{if } [Q_i \geq 0.5 (\bar{Q}) \text{ and } \pi > 0] \\
17 & \text{if } [Q_i \geq 0.5 (\bar{Q}) \text{ and } \pi < 0] \\
10 & \text{if } [Q_i < 0.5 (\bar{Q})]
\end{cases}
\]  

Providing a wage penalty to the gatherers performing in the lowest tail of the distribution (about 1/2 of the mean) provides a scheme which closely approximates that of ordinal ranking (in which the worst one or two players are penalised); although this is a somewhat arbitrary imposition of the weighted average component \(k\) in (9), it more closely matches the historical reality than would imposing a scaled linear relative payments system. One of these farms declined use of the species bonus and instead followed a scheme like that in equation (8), paying a high fixed wage of 27 lps ($4.91) for retained gatherers.

The few ‘spot-market’ boat owners, most of whom reside in Zone 2, often paid gatherers only a predetermined piece rate (PR). Boat owners were flexible in their relations with gatherers and the purchasing shrimp farms, and few tied labour contracts were observed. The total catch was divided between the four crew, with an additional share for the boat. In the mid-1990s the market wage had gatherers receiving 3 lps (about $0.54) per thousand larva delivered for a general wage specification as:

\[
W_{PR} = (3'Q_t \text{ all species}) / 5
\]  

In Zone 3, multiple contractual arrangements existed, depending upon how boat owners changed larva delivery across farms. Some gatherers worked exclusively under either relative payment or piece-rate systems throughout the year, while a sub-group of gatherers were paid under both systems, depending upon the boat owner’s relationship with different shrimp farms.\(^{15}\)

Trends in Gathering Incomes and Welfare

1. Household Statistics. Table 2 incorporates the village averages in each of three zones across the year to describe the impact of larva gathering on the household economy. The contractual variation across zones is clear, as nearly 96 per cent of the
workdays in Zone 1 are associated with relative payments while 94 per cent of the workdays in Zone 2 are associated with piece rates. The fewest days of employment occurred in Zone 1 where relative payments dominate. But given higher yields and earnings, in Village A larva income was a large part of total yearly income. The role of gathering in the local economy was particularly important in the ‘winter’ months when gathering incomes comprised up to 63 per cent of the total household monthly income in Village C; across the year gathering contributed to income smoothing.\(^{16}\) Few households had measurable assets or asset sales affecting income streams.

Contractual variation in gathering catch and incomes appears in the bottom of Table 2. Self-reported daily catch levels are highest in the zone where relative payments dominate, and highest for that contract in each of the villages. The coefficient of variation of catch levels was moderate across the year (less than 2 in

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**Table 2. Larva gathering arrangements in southern Honduras (household dataset from 3 villages)**

<table>
<thead>
<tr>
<th></th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yearly data analysis:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total days larva work:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative payments/FW</td>
<td>96%</td>
<td>6.5%</td>
<td>42%</td>
</tr>
<tr>
<td>Piece rate</td>
<td>4%</td>
<td>93.5%</td>
<td>58%</td>
</tr>
<tr>
<td>Larva workdays as % paid workdays</td>
<td>33%</td>
<td>40%</td>
<td>38%</td>
</tr>
<tr>
<td>Larva income as % total yearly income</td>
<td>56%</td>
<td>37%</td>
<td>44%</td>
</tr>
<tr>
<td><strong>Daily data inputted from monthly household records:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-reported average catch (1000)(^a)/person**</td>
<td>40 (45.5)</td>
<td>10 (10.8)</td>
<td>16 (18.3)</td>
</tr>
<tr>
<td>Relative payments</td>
<td>40 (45.5)</td>
<td>73.1 (41.7)</td>
<td>21 (23)</td>
</tr>
<tr>
<td>Piece rate</td>
<td>3.5 (.71)</td>
<td>9 (6.15)</td>
<td>14 (15.5)</td>
</tr>
<tr>
<td><strong>Average daily larva income</strong>(^b)**</td>
<td>31.63 (31.13)</td>
<td>21.17 (14.5)</td>
<td>38.12 (33.07)</td>
</tr>
<tr>
<td>Relative payments</td>
<td>32.08 (31)</td>
<td>32.84 (29.24)</td>
<td>48.85 (42.49)</td>
</tr>
<tr>
<td>Piece rate</td>
<td>18.02 (9.46)</td>
<td>20.40 (12.70)</td>
<td>30.96 (21.45)</td>
</tr>
<tr>
<td><strong>Safety-first outcomes</strong>(^c)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative payments</td>
<td>22.5%</td>
<td>41.5%</td>
<td>16.6%</td>
</tr>
<tr>
<td>Piece rate</td>
<td>21.2%</td>
<td>18.8%</td>
<td>3.1%</td>
</tr>
<tr>
<td>% month wage income &lt; Absolute poverty line</td>
<td>57.1%</td>
<td>43.2%</td>
<td>26.3%</td>
</tr>
<tr>
<td>Relative payments</td>
<td>63%</td>
<td>50%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Piece rate</td>
<td>71.4%</td>
<td>69%</td>
<td>46.7%</td>
</tr>
<tr>
<td><strong>EU outcomes</strong>(^d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily larva income</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative payments</td>
<td>20.05</td>
<td>22.15</td>
<td>26.28</td>
</tr>
<tr>
<td>Piece rate</td>
<td>16.9</td>
<td>18.37</td>
<td>25.21</td>
</tr>
<tr>
<td>Total wage income</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative payments</td>
<td>15.54</td>
<td>16.07</td>
<td>22.92</td>
</tr>
<tr>
<td>Piece rate</td>
<td>14.37</td>
<td>17.61</td>
<td>19.79</td>
</tr>
</tbody>
</table>

**Notes:**
\(^a\)mean (standard deviation in parentheses).
\(^b\)all numbers in 1993–94 lempiras (5.5 lps = $1).
\(^c\)percent of daily observation below the daily poverty line/disaster level of 17 lps.
\(^d\)CARA number of utiles expected where $EU = E(Y) - 0.5AV(Y); A = .025$.
\(*, ** sub-sample means different at 95, 90% significance.$
each case). Earnings, however, varied greatly due to the inclusion of species bonuses, different days of work and penalties in the relative payments contracts. The household data show the Honduran larva gatherers earned somewhere between 20 and 40 lps ($3.70–7.30) per day on average. Mean earnings from gathering were the highest in Zone 3 where the two contractual regimes existed side by side, while Zone 1 had the highest variation of incomes.

In each village gatherers paid under relative payments earned significantly higher daily earnings than those under piece rates; Figure 2 presents the earnings distribution comparisons for Zone 3. The relative payments contract appears to have shifted the distribution to the right, yet the species bonus to some gatherers created a few high outlier incomes. So the higher variance of relative payments earnings caused a higher coefficient of variation for that income in each zone. An F-test of the ratio of the variances of relative payments to piece-rate earnings rejected the hypothesis of equal variability in each case.17

The bottom of Table 2 turns to the common objective measures of risk exposure discussed in equations (4)–(6). The analysis first concentrates on the larva-gathering

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![Figure 2](image-url)  
**Figure 2.** Incomes by contract Zone 3 (a) Relative payments, (b) Piece rates
activity as the principal source of income, and thus risk, for the household. Government decree 30–93 of June 1993 set 17 lps ($3.09) as the daily minimum wage in non-traditional agricultural export industries. This may be considered a baseline for the minimum consumption agricultural disaster level forming the basis for a safety-first rule against downside risk. Households in Zone 2 apparently had the highest probability of falling below the disaster level (41.5 per cent of the period). However there is strong contractual variation across the larva earnings patterns; in each case those gatherers working under relative-payment schemes had a lower probability of falling below the disaster level. As Figure 2 suggests, the earnings distribution of the relative payments gatherers has been shifted up so they fall below the disaster level less frequently (when fired). The same pattern appears for the other zones (irrespective of environmental factors) in which a higher level of objective risk exposure occurs when gatherers are paid piece rates.

Using a more ‘generous’ national poverty line produced results in which 30–77 per cent of the households fell below the disaster level. Likewise, considering total household monthly wage income against a national monthly extreme poverty line in objective risk exposure means that many families in the sample fall below the disaster level. However, in each case the ranking across zones and contracts did not change.

Relative payments also provide a higher level expected utility for moderately risk averse gatherers under the mean-variance framework of equations (5)–(6). Figure 3 shows the variation in contractual dominance across different degrees of the CARA parameter and a DARA specification. For levels of low to moderate risk aversion (A ≤ 0.025, or relative risk aversion R between 0.53 and 0.96 across the zones’ mean incomes) the expected utility under relative payments is higher, but surprisingly more risk averse individuals prefer piece rates. The dominance of relative payments also holds across many wealth levels under the DARA specification (with R = 1). However, when consideration of the gathering families’ total wage income is used (in the last row of Table 2) some zonal variation appears. Relative payments tend to dominate piece rates up to moderate levels of risk aversion (A ≤ 0.25) in Zones 1 and 3, while piece-rates dominate relative payments at all levels of risk aversion in Zone 2. This follows the pattern predicted in Nalebuff-Stiglitz since in Zones 1 and 3 the production patterns demonstrate high sources of covariate risk while in Zone 2 idiosyncratic sources dominate production risk.

This initial view of actual gathering incomes seems to suggest that relative payments provide the highest expected incomes and utility and lowest objective risk exposure since incomes frequently were larger under this contract. Any moderate variation in incomes across the relative payments sample appear to be compensated or created by the redistributive species bonus provided in the household dataset statistics. Some trends of piece-rates providing less variation and risk exposure to gatherers in Zone 2 (to support the Nalebuff-Stiglitz hypotheses) can be seen. But a clear proof is obscured by the manner in which the relative payments contract was implemented.

2. Farm-level Statistics. Here we use the observed quantity sold by each boat owner to the farms in Table 1 to extrapolate gatherer income under both relative payments and piece rates. The detailed catch data implicitly represents the larva production function of equation (1). The institutional rules and actual market parameters of equations (11) and (12) are incorporated into the earnings projections. Two forms of
relative payments are examined: (i) that incorporating the species bonus rules used in the household data set ‘RP1’ and (ii) a ‘classic’ relative payment scheme ‘RP2’ with a prize of a high fixed wage of 27 lps (that observed by one farm without the species bonus) or a penalty of the going wage of 10 lps (that earned if a gatherer is fired and forced to work in general agricultural labour) if the boat catch was less than 50 per cent of the average of all boats on that day. Finally, boat owner outcomes were determined.

In Table 3 it is clear larva catch gatherers generally would have earned more (and experienced a higher coefficient of variation) under piece rates, apart from the environmental conditions of each zone. Figure 4 shows how the wide distribution of piece-rate returns, and high outliers and some very low returns, create a higher average income with higher risk. This result based on farm-level data partially
Table 3. Projected gatherer income trends across production zones and contracts (extrapolation from purchase quantities 7 shrimp farms)

<table>
<thead>
<tr>
<th>Summary statistics/contract&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Farm 1</td>
<td>Farm 2</td>
<td>Farm 3</td>
</tr>
<tr>
<td>Zone 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RP1&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu = 25.6$</td>
<td>$\mu = 30.8$</td>
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</tr>
<tr>
<td>$\text{CV} = .91$</td>
<td>$\text{CV} = 1.05$</td>
<td>$\text{CV} = 0.67$</td>
<td>$\text{CV} = 0.47$</td>
</tr>
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<td></td>
</tr>
<tr>
<td>RP1&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu = 20.4$</td>
<td>$\mu = 38.3$</td>
<td>$\mu = 22.5$</td>
<td>$\mu = 22$</td>
</tr>
<tr>
<td>$\text{CV} = 1.34$</td>
<td>$\text{CV} = 1.32$</td>
<td>$\text{CV} = 0.61$</td>
<td>$\text{CV} = 0.50$</td>
</tr>
<tr>
<td>Zone 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu = 56.9$</td>
<td>$\mu = 88.2$</td>
<td>$\mu = 39.2$</td>
<td>$\mu = 34.6$</td>
</tr>
<tr>
<td>$\text{CV} = 1.6$</td>
<td>$\text{CV} = 1.41$</td>
<td>$\text{CV} = 1.43$</td>
<td>$\text{CV} = 1.38$</td>
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<td>Safety-first outcomes&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>RP1&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>23.2%</td>
<td>26.5%</td>
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</tr>
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<td>RP2&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23.2%</td>
<td>26.5%</td>
<td>24.4%</td>
<td>6.6%</td>
</tr>
<tr>
<td>PR&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>36.5%</td>
<td>23.1%</td>
<td>43.8%</td>
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</tr>
<tr>
<td>EU outcomes CARA&lt;sup&gt;d&lt;/sup&gt;</td>
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<td></td>
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<tr>
<td>18.9</td>
<td>17.8</td>
<td>20.7</td>
<td>19.3</td>
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<tr>
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<td>23.2</td>
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<tr>
<td>-47.5</td>
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<td>-0.1</td>
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</tr>
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</tr>
<tr>
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</tr>
<tr>
<td>3.9</td>
<td>3.9</td>
<td>4.1</td>
<td>4.1</td>
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<td>4.3</td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>3.9</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Boat owner profits</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>RP1&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu = 483$</td>
<td>$\mu = 769$</td>
<td>$\mu = 379$</td>
<td>$\mu = 228$</td>
</tr>
<tr>
<td>$\text{CV} = 4$</td>
<td>$\text{CV} = 3.9$</td>
<td>$\text{CV} = 1.8$</td>
<td>$\text{CV} = 2.2$</td>
</tr>
<tr>
<td>RP2&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu = 493$</td>
<td>$\mu = 802$</td>
<td>$\mu = 384$</td>
<td>$\mu = 216$</td>
</tr>
<tr>
<td>$\text{CV} = 4$</td>
<td>$\text{CV} = 3.8$</td>
<td>$\text{CV} = 1.9$</td>
<td>$\text{CV} = 2.5$</td>
</tr>
<tr>
<td>PR&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
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</tr>
<tr>
<td>$\mu = 358$</td>
<td>$\mu = 539$</td>
<td>$\mu = 318$</td>
<td>$\mu = 193$</td>
</tr>
<tr>
<td>$\text{CV} = 5.2$</td>
<td>$\text{CV} = 5.4$</td>
<td>$\text{CV} = 1.9$</td>
<td>$\text{CV} = 2.1$</td>
</tr>
</tbody>
</table>

Notes: <sup>a</sup>all numbers in 1993–94 lempiras (5.5 lps = $1); <sup>b</sup>$\mu$ = mean; <sup>c</sup>$\text{CV}$ = coefficient of variation of income.<br><sup>d</sup>RP1 signifies relative payment system with species bonus; RP2 signifies relative payment without species bonus; PR signifies piece rate system.<br><sup>e</sup>signifies percent of daily observation below the daily poverty line/disaster level of 17 lps.<br><sup>f</sup>number of uilles expected where linear expected utility function is described as $E(y) - A*.5*V(y); A = .025$.
contradicts the previous section based on the household dataset. The divergence could emerge from the underreporting of family incomes in the household dataset or the different sample and catch statistics across the two datasets (the mean catch per boat, and imputed catch per person, in Table 1 is well above the self-reported catch levels of Table 2).

With the extrapolations some variations across contracts by zone appear in the objective risk measures. For safety-first considerations relative payments contracts provide a smaller probability of falling below the disaster level in Zones 1 and 3, but in Zone 2 piece-rate contracts are superior in this regard. Here the much higher mean income under the piece-rate contract shifts the whole wider distribution of earnings significantly to the right to provide a safer outcome to gatherers. This lends support to the Nalebuff-Stiglitz (N-S) hypotheses that piece rates reduce risk exposure in areas when there is less covariate risk (Zone 2).

Interesting differences also emerge across the two formulations of the relative payments scheme (RP1) and (RP2) presented here. Generally about 30 per cent of the boats received a penalty each day, with 70 per cent a prize, so that income variation was small. The main source of variation comes from the inclusion of the

![Figure 4. Extrapolated Incomes by contract Zone 3 (a) Relative payments (RP1), (b) Piece rates](image-url)
species bonus (RP1). The bonus raises mean income and variance compared to the straight prize-penalty system of RP2. Since gatherers fall below the set disaster level of 17 lps if they are penalised, the additional variation does little to help risk-averse gatherers achieve safety-first goals of minimising disaster outcomes. Instead it lowers expected utility in the mean-variance framework in Zones 1 and 2. In contrast to Figure 3, the expected utility to gatherers under relative payments in Figure 5 is nearly constant and higher than that under piece rates at higher levels of CARA risk aversion; the contract without a species bonus (RP2) scores highest under both types of risk preferences. The result of more risk-averse gatherers preferring relative payments in Zone 3 supports the N-S hypothesis.

We find that the boat owners always earned a higher mean income using any type of relative payments for the historical market parameters. Earnings were based on the differential species price (10 lps per 1,000 \textit{P. Vannamei} and 3 lps per 1,000 \textit{P. Stylirosis}) of that period, less the imputed wages paid to the gatherers and a fixed gasoline/boat maintenance fee. As mentioned above, the preference for \textit{P. Vannamei} and \textit{P. Stylirosis}.

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\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{EU Larva Income Zone 3 (a) CARA, (b) DARA}
\end{figure}
and the substitutability of hatchery larva (priced at approximately $6.33 lps per 1,000 PV) placed a ceiling on the amount farms paid boat owners and ultimately gatherer wages. Earnings under relative payments were associated with a higher coefficient of variation of earnings in each zone. In all cases except that of the largest farm in Zone 1 boat owners also suffered more days with negative revenue under the relative payments scheme. Across the year the boat owners would earn a loss on 15–25 per cent of the days. However, given the presumably risk-neutral preferences of this group and the potential for very high profit days to offset the few loss outcomes, most boat owners expressed a preference for paying their gatherers under relative performance during this period.

The extrapolations from farm data in Table 3 suggest the welfare of coastal dwellers and gatherers can be affected by incentive-compatible contractual design. Table 3 shows that the relative payments system likely reduces the average returns offered when catch levels are high, and it would not reduce the probability of disaster in areas of high idiosyncratic risk. But it does provide the highest expected utility in an area of high covariate risk. The actual dominance of a relative payment contract with a species bonus in this stage of aquaculture history also stemmed from principals’ preferences and large farms’ need for a timely input supply. Apart from environmental factors, the more competitive market conditions in Zone 2 perhaps allowed for the emergence of the optimal piece-rate contracts.

IV. Lessons for Natural Resource Gathering and Household Welfare

Most of the previous literature on forest and coastal products gathering highlights the goals of income generation and environmental protection. The management of risk in gathering economies have largely been ignored in the debate. Micro-economic theory suggests agents should experience a higher welfare if they are paid under a relative payment system when large covariate shocks are present and many players competing.

The specific case of larva shrimp seed gathering in Central America was examined to test this proposition. The research focused on Honduras, where a booming aquaculture sector stimulated demand for gatherer labour in the 1990s. There an interesting mix of contracts occurred between shrimp farms, boat owners and gatherers with some parallels to local environmental variation. Production Zones 1 and 3 were likely characterised by the highest covariate risk and, interestingly, in these locations relative payment systems emerged.

Overall, Honduran seed gatherers experienced high average incomes with wide seasonal catch and income fluctuations. Actual household survey incomes in Table 1 appeared higher under the relative payment system, but with a higher coefficient of variation. The data suggest some 20 per cent of gatherers under relative payments, and 30 per cent of those under piece rates, face high objective risk exposure if they were to rely only on larva-gathering income across the year. However the household data incorporated very low catch levels and a redistributive species bonus introducing variation into the income scheme. Alternative data from farm purchase records, with higher reported catch levels, offered surprising results. In this case gatherers would have experienced higher mean incomes everywhere, and a lower probability of disaster in Zone 2, had they been paid under piece rates. But following
the Nalebuff-Stiglitz logic, relative payments provided higher expected utility to gatherers at moderate to high levels of risk aversion; also, a relative payments scheme with a species bonus offers more risk than that without the redistribution. Boat owners stood to earn more profits under relative payments given the production trends and prices of this period. So the predominance of relative payments incentives schemes during this period could be explained as a risk-sharing device among wealthier boat owners as principals and poorer gatherer agents.

But the design of optimal natural resource contracts may revolve around not only risk but also the industrial organisation in which gathering occurs. The shrimp farms’ production risk and need for timely inputs, the availability of substitutes for the gathered product, and different risk preferences of boat owners were all factors that possibly affected the terms, and ultimately the optimality, of contracts across locations. Transaction costs created by product perishability may have affected contracts differently across locations. Incorporation of these issues into the analysis of gathering economies offers an extension for future empirical research. But new risks (such as animal disease) emerged to change contract choice; so that ultimately the Honduran industry shifted towards substituting towards hatchery larva for input provision. This means environmental management of the primary industry has ripple effects on secondary industries such as gathering.

Elsewhere, even apart from technological change, environmental degradation is hurting the welfare of some coastal communities by affecting the natural resource base upon which gatherers survive. Some lessons of how to design employment contracts in the face of this risk emerge from the Honduran study. First, we found that relative payments offered the highest mean income in the household dataset with low catch yields. Thus when negative covariate environmental shocks (such as droughts) are the primary source of yield variation, managers should use this institution for incentive compatibility. In areas only affected by localised, and mutually-verifiable, shocks such as water pollution and habitat degradation, piece-rate schemes make sense.

**Acknowledgements**

The author gratefully acknowledges the financial support of the John D. and Catherine T. MacArthur Foundation, the Inter-American Foundation and the Organization of American States in the data collection process. Helpful comments by Brad Barham, Michael Carter, Andy Gill, Bob Meade, Robert Michaels, Jeff Nugent, Gerald Shively and two anonymous referees are also appreciated.

**Notes**

1. For an overview of conditional self-insurance and other forms of risk management in agrarian settings, see Udry (1994) and Carter (1997).
2. Fish fry (seed) gatherers work in Central America, and in Ecuador an estimated 50,000 larveros support that mariculture industry (Olsen and Arriaga, 1989). Studies of Asian milkfish fry gatherers (Smith and Panayatou, 1984; Chaur-Shyan, 1986; World Shrimp Farming, 1992) report that over 100,000 gatherers collect fry in the Philippines, Taiwan and Bangladesh. Incorporating gatherers in other aquaculture nations (Honduras, Brazil, India, parts of Africa) brings the estimate up to a quarter of a million people.
3. Chong et al. (1982) and Lee, C. S. (1983) provide two of the few analyses of a fish fry industry (in Taiwan) where markets and exchange are well developed. They demonstrate that the price of milkfish fry is significantly affected by supply, with strong seasonal variation causing price instability. Sutinen et al. (1989) argue the larva market for shrimp mariculture in Ecuador follows free-market conditions; falling real larva prices in the mid-1980s were related to increased fry supplies, although hatchery seed demonstrated a growing role.

4. Since the onslaught of viral diseases in mariculture, the creation of disease-resistant strains of hatchery seed has increased their substitutability with the wild input.

5. In fact, the boat owners could be seen in a dual role as both agents of the shrimp farms and principals to the larva gatherers. Since incomplete data exist on the first role of the boat owner, such a nested principal-agent problem was not considered here; the boat owner’s role as a labour recruiting principal is the focus.

6. Previous fisheries studies assume monotonically increasing effort levels of fisherpeople in open access settings (Gordon, 1954; Anderson, 1986). Shrimp larva gathering is a unique activity in which human effort causes more harm to the fish by-catch than the shrimp itself. The biological maximum sustainable yield point occurs well beyond the economically feasible levels of human extraction, with habitat and climatic factors playing important roles in shrimp sustainability (Smith and Panayatou, 1984). Shrimp is a renewable natural resource, yet unlike many marine species, *Peneaus sp.* (P. *Vannamei* and P. *Stylirosis*) (an ‘r’ population) have a high natural mortality and multiply extremely rapidly. Larva gathering can damage the by-catch of other fish species, but this problem is avoidable with appropriate equipment.

7. Turner (1989) demonstrates a strong association between mean shrimp larva catches and both regional factors (such as latitude) and local habitat and vegetation cover. Chaur-Shyan (1983) notes that mean yields are associated with coastal water pollution levels; however, year-to-year and monthly variation follows meteorological and oceanic changes affecting the spawning and distribution of eggs.

8. For the moment principals are assumed to sort workers and design contracts. The issue of worker self-selection is plausible but not highlighted here as earlier tests provided evidence of labour market segmentation (Stanley, 1999).

9. In this type of ranking boats are ordered according to the quantity of larva delivered over a week period; a cut-off rule (separating the bottom third or those well below the mean) is used to separate the winners and the losers.

10. Good workers are kept ‘on-call’ by the boat owner with extra incentives in a pseudo labour-tying arrangement. Owners explained they gave pre-work food loans and medical help to their gatherers ‘*para que no se vayan*,’ ‘*para no perderlos*’ and ‘*para que no se retire*’ (‘so that they don’t go’, ‘to not lose them’ and ‘so they don’t retire’).

11. The author collected data in three zones of southern Honduras over a period of 15 months. The zones, and six specific villages, were identified by informants from community organisations and shrimp industry representatives. The first dataset tracks household income and work patterns. A sampling frame of residents by occupation was developed from health records, from which a random sample of 160 households was selected in three focus villages. Approximately 10 per cent of selected households refused to participate or migrated during the course of the year, for a total sample of 145. Of this 105 households were dedicated to gathering. Data on the households’ yearly income and employment were collected in weekly visits by 15 trained enumerators. The author conducted initial and exit interviews with households and supervised enumerator work through weekly spot check visits. Visits to three parallel control villages also incorporated income data on 90 households. The second dataset was developed from larva purchase data shared by managers of seven different-sized shrimp farms. The larva purchase records included supplying boat owner, larva quantity and species composition, with no mention of gatherer name or income. Each farm indirectly employed two to 13 boat owners and purchased larva between 100 and 200 days in 1993.

12. Water quality along the Choluteca River (part of gathering sites for Zones 1 and 2) is considered the worst in the region. Discharges from both mariculture and upstream municipal wastes are at fault (Teichert-Coddington, 1999).

13. For this interpretation of the F-ratio, see Johnson et al. (1987), ch. 6.

14. The hypothesis that the subset of coefficients, i.e. idiosyncratic effects in Zone 3, were zero and not significant was tested by a computed F-statistic measuring the differences in the residual
sum-of-squares in a full and smaller regression (Johnson et al., 1987: 123). The F-statistic of 1.82 was not significantly greater than the critical value of 4.75 (for 1 and 12 degrees of freedom), so the hypothesis could not be rejected. Similar hypothesis tests were done for Zones 1 and 2.

15. This change in gathering contracts across the year most likely occurred due to shrimp farm stocking needs and demand, with smaller stocking rates and fewer boats commissioned during the dry season.

16. In separate calculations to match equation (3), we found that the gathering income had a small, but potentially important, role in stabilising coastal household incomes. The monthly larva income figures were negatively correlated ($-0.06$ to $-0.29$ Pearson correlation) with other sources of income (fishing, off-farm labour, own agricultural activities) in each of the villages. Additionally, the variation of the larva monthly income appeared on par with trends from other sources of work. The monthly coefficient of variation of larva-gathering incomes was $0.85–0.97$ in the three villages, which is lower than the variation associated with agricultural crop sales and fishing.

17. For Zone 1, the ratio of the variances produced a F-statistic of 10.76 (above the 95% critical level of $F = 3.28$ for 184, 7 d.o.f.); Zone 2 $F = 5.28$ (above the 95% critical level of $F = 1.69$ for 16,227 d.o.f.); Zone 3 $F = 3.92$ (above the 95% critical level of $F = 1.35$ for 98, 137 d.o.f.).

18. The Honduran National Planning Institute (SECPLAN) used a daily poverty line of 26.6 lps (for a family of five) based on the consumer price index at the time of this study. Families earning a total income less than 800 lps per month would be classified in extreme poverty. Given a sample average household size of six people, this figure may serve as a more appropriate disaster level.

19. Those gatherers with the lowest catches received the same low prize in both the RP1 and RP2 schemes. The species bonus clearly was given only to ‘retained’ gatherers, those achieving the prize of the higher income. In raising incomes, the species bonus, however, would allow more gatherers to rise above a higher income threshold disaster level, such as the daily national poverty line of 26.6 lps established by the Honduran government.

References


**Appendix. Comparing Relative Payments and Piece-Rates**

The dynamics around $\psi$ can be simplified into a system in which a comparison to the agent’s output and the mean output creates a linear function continuum of prize and penalty outcomes. For performances greater than the mean, a bonus leads to a much
higher wage while performances below the mean imply a penalty (akin to a firing penalty with small alternative wages). In this case the wage expression becomes:

\[ Y_{RP} = \left[ \overline{B}_1 + c(q_i(e_i, \theta, \eta_i) - \overline{q}(e_i, \theta, \eta_i)) \right] \] (A1)

where \( \overline{B}_1 \) = base pay, \( c \) = incentive weighting parameter, \( q_i \) = agent gathering quantity, \( \overline{q} \) = mean gathering quantity.

Agents set effort so that the marginal increase of his/her gap (weighted by \( c \)) just equals the marginal disutility of effort. With this contract, expected earnings and variability of gathering relative payments become:

\[
E(Y_{RP}) = (B_1 + c\overline{q}) \\
Var(Y_{RP}) = c^2 \text{var}(q - \overline{q}) = c^2(\text{var}(q_i) + \text{var}(\overline{q}) - 2\text{cov}(q_i, \overline{q}))
\] (A2)

Assuming no ex-post transfers, expected earnings and variability of gathering earnings (without cross-period correlation) under piece-rates are:

\[
E(Y_{PR}) = af(e_i) \\
Var(Y_{PR}) = a^2 \text{Var}(q_i)
\] (A3)

After reorganising and simplifying, we can see that the variance of incomes under relative payments (RP) will be lower than that under piece rates (PR) if:

\[
(1 - c^2/a^2) \text{var}(q_i) + \text{var}(\overline{q}) - 2\text{cov}(q_i, \overline{q}) < 0.
\] (A4)

The left-hand side of the equation becomes smaller with a larger covariate shock (\( \theta \)) between the individual’s and mean outputs, while the variance of the mean output \( \overline{q} \) becomes smaller as group size grows (Martin, 1997). Here the differential between the common share \( a \) and the incentive weighting \( c \) also become important; as the parameter used in relative payments equals that under piece rates the first term on the left would disappear.