Financing a New Technology in Small-scale Fishing: the Dynamics of a Linked Product and Credit Contract

Xavier Giné
World Bank

Stefan Klonner
Yale University

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Abstract

Based on a case study in a Tamil fishing village, this paper analyzes the dynamics of a particular credit-cum-marketing arrangement that is frequently encountered in small-scale fishing in South-Asia. A trader repeatedly lends to a credit-constrained entrepreneur in return for the privilege to market the entrepreneurs output. The loan does not bear any interest and no lump reduction of the principal occurs. Instead the trader keeps a stipulated share of the daily sales revenues as commission and for the gradual reduction of the principal. The entrepreneur uses the initial loan to switch to a new technology and can end his relationship with a trader on any day by repaying his debt. The realization of an entrepreneurs daily output is stochastic but positively related to his ability to handle the new technology. The entrepreneurs ability is unknown ex ante but gradually inferred through a Bayesian updating process. When there is a population of risk-neutral entrepreneurs and traders, and each trader earns zero expected profits, the model predicts that in equilibrium, (i) an entrepreneurs actual debt may exceed the debt level desired by the trader, (ii) actual debt as well as the debt level desired by the trader is increasing over time on average, (iii) the distribution of individual debt becomes more dispersed over time, (iv) each traders actual profit rate converges to zero. These theoretical predictions are found to be consistent with the data from the study village.

1 Introduction

The adoption of new technology in rural parts of developing economies has received much recent attention by economists. It is generally recognized that the transformation of technology plays a fundamental role in the development process and much of the recent literature has focused on how individuals can learn to use a new technology efficiently, which is crucial for the individual decision on whether to adopt a new technology or not (Conley and Udry, 2002; Jovanovic and Nyarko, 1996). Most of this literature, however, has not been concerned with the financing of such, typically capital-intensive technologies, even though small-scale farmers and fishermen often face credit-constraints and thus may not have access to a more profitable but costly technology.

The present paper portrays a contractual arrangement that serves to finance a new technology in small-scale fishing. It highlights two elements which play a crucial role in situations where new technologies are introduced to small-scale enterprises in the primary sector, namely risk in production and uncertainty about the entrepreneur's ability to handle the new technology, and explores how these factors affect the borrower-lender relationship. It is based on a case study in a coastal village in Tamil Nadu in January 2002, where semi-traditional, small-scale fishing techniques have prevailed until very recently. Until then, most of the village's fleet consisted of so-called kattumarams, raft-like crafts made of a number of pieces of logs which are tied together with two cross beams at the two ends (Platteau et al., 1985). These traditional boats are powered by small outboard motors and operated by two to four fishermen. It was only in the year 2000 that the first so-called fiber boat appeared in the village, a plastic vessel of about 25 feet length typically operated by three to five fishermen. Its more streamlined design, lighter weight, and stiffness allow faster cruising with less fuel consumption. Its wider radius of operation and its ability to cope with rough sea result in fish catches about three times as big as those of a kattumaram. However, it costs 60,000 to 70,000 Rupees, or three to four times the cost of a kattumaram, which amounts to 15,000 to 20,000 Rupees.

In the village of study, the bulk of the new fiber boats have been financed through local middlemen who engage in the marketing of fish. Since the fish is mostly sold by auction, we will refer to them as auctioneers. The contractual relationship between an auctioneer and a fisherman who purchases a fiber boat is uniform throughout the village and can be summarized as follows: The auctioneer hands out a loan that covers the cost of the boat.

The fisherman, in turn, obliges himself to sell each day's catches exclusively through that auctioneer who keeps a stipulated percentage of the sale's revenue as commission and for the reduction of the fisherman's debt. Other than this share there are no stipulated payments between the parties. At times, the debt balance is renegotiated and the boat-owning fisherman may receive further loans, typically of a smaller amount than the initial loan. A simpler form of the above-described credit-cum-marketing share-arrangement already prevailed in the village when the kattumaram was the common equipment.

While there is a body of literature on credit-cum-labor share arrangements between boat-owning and laborer fishermen (e.g. Sutinen, 1979; Platteau and Nugent, 1992), credit-cum-marketing share contracts for the purchase of equipment are only briefly mentioned in the existing literature (Platteau et al. 1985), and have not received much attention[1].

The present case study is thus of particular interest since it explores how a modified version of an indigenous interlinked arrangement performs in financing a capital-intensive, modern technology.

Rather than analyzing the contractual arrangement prevailing in the village, we provide an understanding of how uncertainty about the borrower's ability to handle a new and risky technology affects the borrower-lender relationship. More importantly, the theory presented is consistent with the facts shown in the data.

The most salient feature of the data, is that at the beginning of the auctioneer–boat-owner relationship and thereafter, the outstanding debt differs considerably. In addition the debt levels over time of different boat-owners may well diverge. Indeed, the debt level in the long run is related to the boat-owner's ability to fish.

The model featured in this paper offers a very clear explanation of the diversity in debt values at any point in time. Consider an environment of perfect competition among auctioneers and assume that they have unlimited access to capital. In equilibrium, the profit rate of each auctioneer with any given boat-owner has to equal the opportunity cost of funds. Therefore, such dispersion in the debt levels can only be explained through differences in the sales revenue each boat-owner generates. If an auctioneer knows the ability of a fisherman who starts fishing with a fiber boat, this implies that debt should

[1] In their study of three fishing villages in Kerala, Platteau et al. (1985) find that only in one of the villages auctioneers play more than a marginal role for financing fishing gear. Instead, moneylenders who charge a fixed interest rate and credit transactions within the fishermen's community play a major role.

be proportional to expected sales. No auctioneer would be willing to lend more than that because, then, he would initially derive less profits than his opportunity cost and, since any boat-owner is free to switch auctioneers once the previous debt is settled, the fisherman would leave the auctioneer when the debt was reduced to the break-even level. On the other hand, if the auctioneer was to lend less, the boat-owner would ask for more debt to buy additional gear or to consume more at an earlier point in time, and competition among auctioneers would forcing him to give in.

If, on the contrary, ability is not known but rather inferred over time, the optimal debt level is adjusted accordingly. In this scenario, the profitability of the relationship between the auctioneer and boat-owner converges to the opportunity cost. This is precisely what we see in the data. The initial profitabilities are dramatically different from the opportunity cost of capital. However, the variance of the observed profitabilities decreases *over time* as profitabilities cluster around the opportunity cost of capital.

The rest of the paper is organized as follows. Section 2 describes in detail the village of study, focusing in particular on the observed fishing technologies and the way in which they are financed. Section 3 presents the data and documents some of its salient features. Section 4 models the auctioneer–boat-owner relationship, first under the assumption that the boat-owner's ability to handle the new technology is known and later under the competing scenario that the ability is inferred over time. Section 5 tests the main predictions of the model using the data. Finally Section 6 concludes.

2 Background

In this section we first describe in detail fishing activity of the village of study and then, in Section 2.2, we turn to the financing of the different technologies.

2.1 Small-Scale Fishery

The village of study is located on the southern part of the coast of the gulf of Bengal, close to the pilgrim center Tiruchendur. Its population numbers around 1,500 of which about 200 men regularly sail on one of the 55 boats that operate from the village. At the time of the survey in late January 2002, there were 19 kattumarams, 35 fiber boats, and one mechanized boat. Kattumarams and fiber boats are powered by an outboard engine and are operated by a crew of two to four and two to five, respectively. The mechanized boat has an inboard diesel engine and requires a crew of three to five. Our survey contains data on the mechanized and 35 fiber boats. Since the village has neither a harbor nor a jetty, only beach-landing boats are operated. During the monsoon months in summer there is a so-called vollam-season when mechanized vollam-boats with a crew of five from other villages land on the village's beach and market their catches there. Local kattumaram and fiber boat fishing continues during that period. According to local fishermen, fish is plentiful enough that no competition with the migrating mechanized boats arises. Instead, the local economy benefits from the demand generated by the migrant crew members and the increased marketing activity in the village. Auctioneers and local fishermen indicated, however, that a year-round operation of the highly capital and labor-intensive vollams would not be profitable in the village.

The local market for fish outside the vollam season is now described. Between 7 and 11am the fishing boats land on the beach, where the auctioneers wait. The fish is brought from the boat to the beach's auction place, where the auctioneer who markets the boat auctions the catches to usually between 5 and 10 bidders. These include local merchants who sell the fish on local markets as well as agents of big marketing firms in Kerala, which ship their purchases in trucks to secondary markets in Tiruchendur. The catches, which come from the boats in plastic boxes or baskets, are not weighed, instead the bidders determine their bid by the appearance of each unit auctioned. Each auctioneer keeps track of his sales by keeping a book for each boat. He may or may not collect the money from the winning bidders on the day of the auction. Nonetheless, he reimburses each client boat-owner in the early afternoon after adding the figures. At the end of the year, the auctioneer updates the debt balance taking into account the yearly value of sales and gives the book containing the daily sales to each client boat-owner. This way, the fishing history of each boat-owner becomes public.

Unlike the kattumaram, which is the traditional fishing technology in southern India, and the mechanized boat, which has been introduced in Kerala in the 1960s (Kurien, 1994), the fiber boat is a recent technology. The fiber boats used in the village are all of the same make and come from a domestic manufacturer. Unlike the first diesel-powered boats that replaced the kattumaram in Kerala in the late 1950s (Platteau et al., 1985), it can cope with rough surf and is, at the same time, faster and more economical than a kattumaram, which is operated with the same outboard engine. According to local fishermen and auctioneers, with the same number of crew, a fiber boat's landings are on average about three times as big as those of a kattumaram. Its importance for village economies on the coast is documented by the fact that the national newspaper The Hindu recently printed a 700-words article on this craft (The Hindu, 2001). Given the yields of fiber-boat fishing, every owner of a kattumaram in the village we interviewed assured that he wanted to switch to a fiber boat as soon as possible. It has to be mentioned, however, that fishing on a fiber boat requires a different set of skills than those needed to operate a kattumaram. For that reason it is common practice among the buyers of fiber boats in the village to hire migrant laborer-fishermen from Kerala as crew members who have previously gathered some experience with the new technology.

The cost of a new fiber boat is 60,000 to 70,000 Rupees, while a kattumaram costs 15,000 to 20,000. The cost of a new outboard motor is Rs. 50,000 to 60,000. The first fiber boat appeared in the village in April 2000. In most cases, owners of kattumarams shifted to fiber boats and continued to use the outboard engine of the kattumaram.

In the village of study, fishing is typically a family enterprise. If a family owns a craft, typically at least two family members (two brothers or father and son) sail on the boat. The rest of the crew consists of laborer-fishermen who are usually attached to the boat-owner through an interlinked credit cum labor arrangement. We did not observe joint ownership of boats as it is reported in Platteau et al. (1985) in small-scale fishing in Kerala. We do observe however, families with more than one fiber boat. In this case, the catches from the family's boats are marketed through the same auctioneer, who does not keep separate accounts for each boat.

2.2 The Financing of Fishing Boats

We first describe the traditionally prevailing credit and marketing arrangement that owners of kattumarams in the village have, and later turn to the to the contractual arrangement used to finance fiber boats.

A fisherman who wants to acquire a kattumarams approaches one of the village's auctioneers, who gives a loan of 15,000 to 20,000 Rupees for the purchase of the gear. In return, the boat-owning fisherman sells all his catches through that auctioneer, who keeps 5 percent of the value of the sales[2]. No fraction of the catches is kept by the auctioneer

[2]This number is also reported by Platteau et. al (1985) in the context of financing of mechanized boats in the Keralite village of Sakthikulangara. They state that, out of the five percent, "3% represents the interest payment while the rest stands for auctioning commission" (p. 218).

for the reduction of debt. The boat-owning fisherman may approach the auctioneer for further loans, be it for consumption or productive purposes, such as nets or repair costs. Such extra debt is usually interest-free and repaid in one or several lump payments.

The arrangement for fiber boats looks somewhat different: as above, the auctioneer gives a loan toward the purchase of a boat in return for the exclusive marketing rights on the catches of that boat. In our sample, the individual debt balance after purchasing the fiber boat ranges between Rs. 40,000 and 97,000, where, in seven cases, this amount includes Rs. 1,700 to 27,000 of debt the fisherman had had with the auctioneer before purchasing the fiber boat. One of the six auctioneers also markets the catches of the three fiber boats in the village which have not been financed by auctioneers. From these sales he keeps 3 percent as commission. As for the kattumarams, the boat-owning fisherman may approach the auctioneer and ask for further loans. If these are granted, they are interest-free and are added to the fisherman's current debt balance. No lump repayments of debt occur.

All owners of fiber boats whom we interviewed expressed that they did not intend to reduce their debt to zero and thus save 4 percent on the commission. Instead they pointed out that it was essential to have a source of revolving credit. What makes the case of the village particularly interesting is that there has been considerable entry into the business of local fish marketing cum lending. Only half of the six auctioneers who have financed fiber boats have been in the business for more than three years. The three newcomers, who account for about two thirds of the fiber boat purchases in our sample, are villagers who have retired from occupations abroad and in the Indian army, respectively, and seek a profitable way to invest their retirement lump sum settlement. Of the three established auctioneers, one also receives funds from outside through his sons who work abroad. There thus is a large supply of capital on the side of local auctioneers. Further, a boat-owner who has a debt balance with an auctioneer can switch to another of the village's auctioneer without additional cost if he settles his debt balance. Typically the auctioneer he switches to settles his previous debt. From what we observed, it also seemed that the auctioneers in the village do not communicate much with each other. It is, moreover, noteworthy that neither banks nor moneylenders and cooperatives play a role in the financing of fishing boats in the village, an observation that is in stark contrast to Platteau et al.'s (1985) findings in three Keralite villages. Boat-owners in the village claim that moneylenders are too expensive and that banks, which would in principle offer competitive interest rates, do not collateralize fishing boats. Taking all this together, there is evidence that there is competition among the village's auctioneers and that auctioneers are a relatively "cheap" source of credit from the boat-owners' perspective[3].

3 Data

For each household that acquired a fiber or a mechanized boat before January 20, 2002, and has debt with an auctioneer, we recorded all loan transactions of the household with its auctioneer, the sales revenue of its boat's (or boats', respectively) daily catches between November 1, 2001 and January 24, 2002, as well as the household's aggregate sales stemming from the fiber boat in 2001.

As mentioned in a previous section, there are 35 fiber boats in the sample. Of these, 32 were bought by local fishermen and three by villagers whose major occupation is outside the local fishing business. Of the 32 fiber boats, 28 were financed by six local auctioneers and four by a German charitable organization[4], labelled Auctioneer 5 in Table 1. These fiber boats are owned by 28 families: 23 families own one fiber and 5 families two. We thus have information for a total of 28 families. We drop, however, 2 families because we lack their sales values.

Table 1 provides some descriptive statistics of the boat-owner characteristics, classified by the auctioneer that markets their fish. Three of the village's seven auctioneers who entertain credit relationships with fiber-boat owners keep 17 percent of the value of the boat's sales out of which 10 percent is used to reduce the debt balance and 7 percent is kept as commission. For three other auctioneers, these numbers are 18 percent, 10 percent and 8 percent, respectively. Finally, Auctioneer 5 (the German charitable organization) requires 20 percent for debt reduction and 4 percent in commission. Taking into account the number of clients each auctioneer has, it is clear that most boat-owners (64 percent)

[3] If there is perfect competition among both moneylenders and auctioneers and both types of lenders face identical opportunity costs of capital, one would expect that a moneylender cannot do better than an auctioneer because, thanks to the marketing inter-linkage, the latter can costlessly monitor part of the boat-owner's activity.

[4] Two of the three villagers who bought a fiber boat and are not active in the local fishing business sail on international freight ships and see the boats as distraction during the vacation period they spend in the village. The charitable organization that financed four fiber boats has the objective to help poor and marginalized villagers.

fall under the 10-7 contract.

Table 1: Characteristics of Boat-owners by Auctioneers

	1	2	3	4	5	6	7
Contract Shares (percent)							
Commission	7	8	8	7	4	7	8
Debt Reduction	10	10	10	10	20	10	10
Days in the relationship							
Mean	264	343	29	244	68	346	23
Std. Deviation	86	64	–	174	17	249	–
Debt in December 31st, 2001 (Rs.)							
Mean	60,652	60,000	105,000	47,600	108,209	62,500	–
Std. Deviation	36,743	14,142	49,497	35,473	56,330	38,717	
Value of Daily Catches (Rs.)							
Mean	1077	1392	1185	1017	740	1091	665
Std. Deviation	377		236	365	121	524	575
Coefficient of Variation of Daily Catches							
Mean	1.106	0.9884	0.8717	1.1305	1.1174	1.1248	1.3365
Std. Deviation	0.1607	–	0.0343	0.1608	0.1455	0.1676	0.5751
Number of Obs.	7	2	2	5	4	4	4

In addition, four of the seven auctioneers have had clients on average for a little less than a year, while Auctioneers 3 and 7 just started the business and have thus had clients for less than a month.

The outstanding debt in December 31st, 2001 displays quite a bit of dispersion across boat-owners and auctioneers. There is no data for Auctioneer 7 because he started marketing fish in January 2002.

It is well known that fishery is a risky endeavor. The amount caught as well as the price per quantity unit of fish achieved in the auction on any given day can vary dramatically. We do not have separate price and quantity data for the catches, but the total figure for the sales revenue. The individual coefficient of variation ranges between 0.85 and 1.4 while the mean coefficient of variation across boat-owners who are clients of the same auctioneer range between 0.87 and 1.34. Excluding Auctioneers 2 and 3 because of few observations, we tested whether the C.V. means were significantly different across auctioneers. In all cases, we could not reject the null hypothesis of equal means.

To analyze the magnitude of aggregate vis à vis idiosyncratic fluctuations in daily catches, we run the following fixed effects panel regression:

$$y_{it} = \delta_t + \alpha_i + \epsilon_{it}, \tag{1}$$

where y_{it} is the value of a daily catch in day t by boat-owner i, the parameter δ_t captures the aggregate effect at date t while α_i measures the ability of boat-owner i. We thus assume that there is no learning, but rather that each boat-owner is endowed with a level of ability α_i.

We then characterize the aggregate shock process by running the following AR(1) regression[5].

$$\delta_t = \rho\delta_{t-1} + \beta b_t + u_t, \tag{2}$$

where b_t measures how many boats are fishing on any given day. The results of the regression, given in Table 2, show that the aggregate shocks follow a stationary process with positive autocorrelation.

Finally Figure A displays the estimated and fitted aggregate shocks over time. It becomes evident that aggregate fluctuations due to weather or sea conditions are sizeable.

[Figure A here]

4 The Model

We start by modelling the technology. Consider the owner of a fishing boat, B say. On any day t, his fish catches in real terms are a dichotomous random variable, Y_t say, where

$$Y_t = \begin{cases} 1 & \text{with probability } \theta, \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

In words, the boat-owner catches either one unit of fish or nothing. The former event occurs with probability θ, where the parameter $\theta \in (0, 1)$ reflects the fishing ability of the boat-owner. The price of one unit of fish is fixed and equal to unity. We thus abstract from price uncertainty.

[5] We tried other specifications but AR(1) produced white noise errors.

Table 2: AR Regression of Aggregate Shocks

		T-Stat
Number of Boats b	19.07852 (8.363627)	2.28
Constant	-194.948 (179.6344)	-1.09
AR Coefficient	0.440423 (0.113288)	3.89
SE of Error σ_u	523.2153 (45.23965)	11.57
N. Obs.	85	

SE in parenthesis.

We now turn to the linked credit-cum-marketing arrangement between B and a risk-neutral auctioneer, A say. Suppose that at the beginning of day t, B has an outstanding level of debt of D_t. According to the terms of the contract, A keeps the fraction $\gamma + \mu$ of the sales revenue, where γ is a commission which covers the auctioneer's cost of capital while the fraction μ is used to reduce the principal D_t. We assume that A has access to capital at the given interest rate r per day and maximizes expected profits. Further, based on the discussion of Section 2, we assume that there is free entry into the occupation of marketing the fish and lending, resulting in zero expected profits[6].

Thus far, B's debt would be reduced by μ on each successful day and thus it would eventually be completely repaid. As noted in the previous section, however, the debt level is renegotiated and increased after varying time periods. With competition among auctioneers, we assume that B has the opportunity to switch to another auctioneer, A' say, at the end of any day provided A' is willing to settle B's debt with A. The boat-owner

[6] The assumption of perfect competition among moneylender/traders has previously been made by Bell and Srinivasan (1989) in a model of interlinked credit and marketing in agriculture.

B may be willing to switch auctioneers if the new one grants her additional credit. We denote by V_t as the amount that A' has to pay A in order to settle B's debt. Indeed, V reflects in equilibrium the expected present value of future claims (commissions) that A has against B. Thus, after each day, A will be indifferent between keeping B as a client or losing her to A' for the amount V_t. If the equilibrium V_t is larger than the level of debt D_t, B will be granted a new loan of x_t Rupees. As in the data, lumpy repayments of the principal by B do not occur. This completes the transactions on day t. The timeline of events is given in Figure 1.

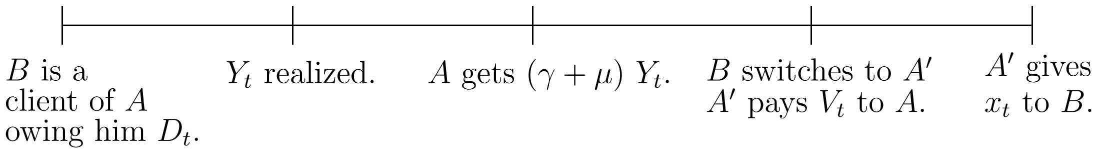

Figure 1: Timeline of events on day t

Notice that we abstract from issues like risk aversion and effort on the side of the boat-owner, and instead focus on the uncertainty about a fisherman's ability to handle the new technology in an environment where fish catches are stochastic.

4.1 Full-Information Case

We start with the useful benchmark where B's fishing ability θ is public knowledge. One variable of interest is the amount of debt, denoted $D^*(\theta)$, that an auctioneer making zero profits is willing to extend to a boat-owner of ability θ. Intuitively, as long as B has some debt with A, A will earn the fraction γ of the value of each day's catches. Perfect competition among auctioneers implies that any auctioneer advances loans whose present value is equivalent to the present value of the infinite stream of γ-payments. More formally, it must be the case that,

$$D^*(\theta) = E\left[\sum_{t=1}^{\infty} \left(\frac{1}{1+r}\right)^t \gamma Y_t\right] = \frac{\theta\gamma}{r}. \tag{4}$$

We will refer to $D * (\theta)$ as the "steady state debt" for a boat-owner of ability θ.

We can now write V in more detail. This function captures what an outside auctioneer A' has to pay to current auctioneer A to settle the boat-owner's debt D. Essentially, it corresponds to the expected stream of income to auctioneer A of having boat-owner B with ability θ as a client. We therefore write $V \equiv V_A(D;\theta)$. Once the boat-owner becomes the auctioneer A' new client, the auctioneer A' agrees to pay x to the boat-owner. After production, if the boat-owner has been successful, the debt is reduced by fraction μ and the auctioneer collects fraction γ. Otherwise, the debt remains at the new level of $D+x$. Intuitively, no auctioneer will want to lend more than the level given by $D^*(\theta)$. Thus, if the boat-owner has debt D satisfying $D \leq D^*(\theta)$, then $x = D^*(\theta) - D$, otherwise if $D > D^*(\theta)$, then $x = 0$. More formally,

$$\begin{aligned} V_A(D;\theta) &= -x + \frac{1}{1+r}\left[\theta\left(\gamma + \mu + V_A(D-\mu+x;\theta)\right) + (1-\theta)V_A(D+x;\theta)\right] \\ & \quad \text{where} \quad x = \max\{D^*(\theta) - D, 0\} \end{aligned} \tag{5}$$

Proposition 1 *If the ability θ of a boat-owner is public knowledge, an auctioneer makes zero expected profits if, and only if,*

$$V_A(D;\theta) = \begin{cases} D & \text{if } D \leq D^*(\theta) \\ \frac{\theta}{r}\left[\gamma + \mu\left(1 - \left(\frac{\theta}{r+\theta}\right)^n\right)\right] + \rho\left(\frac{\theta}{r+\theta}\right)^{n+1} & \text{otherwise,} \end{cases} \tag{6}$$

where $n = int\left(\frac{D-D^*(\theta)}{\mu}\right)$ and $\rho = D - D^*(\theta) - n\mu$.

For the case considered here where ability θ is known, the above functional equation has a closed form solution. We provide it in the next proposition.

Proof. Let the debt level be $D < D^*(\theta)$, then, according to Equation 5 we can write,

$$V_A(D;\theta) = D - D^*(\theta) + \frac{1}{1+r}\left[\theta\left(\gamma + \mu + V_A(D^*(\theta)-\mu;\theta)\right) + (1-\theta)V_A(D^*(\theta);\theta)\right].$$

We can now write $V_A(D^*(\theta);\theta)$ as,

$$\begin{aligned} V_A(D^*(\theta);\theta) &= \frac{1}{1+r}\left[\theta\left(\gamma + \mu + V_A(D^*(\theta)-\mu;\theta)\right) + (1-\theta)V_A(D^*(\theta);\theta)\right]. & (7) \\ &= \frac{\theta}{\theta+r}[\gamma + \mu + V_A(D^*(\theta)-\mu;\theta) & (8) \end{aligned}$$

Therefore, using Equation 7 we have that

$$V_A(D;\theta) = D - D^*(\theta) + V_A(D^*(\theta);\theta) \quad \text{and thus} \quad V_A(D^*(\theta)-\mu;\theta) = -\mu + V_A(D^*(\theta);\theta). \tag{9}$$

Using this last result in Equation 8 and simplifying we obtain

$$V_A(D^*(\theta);\theta) = \frac{\theta\gamma}{r} = D^*(\theta). \tag{10}$$

Thus, $V_A(D;\theta) = D$ for $D \le D^*(\theta)$.

Now let $D = D^*(\theta) + n\mu + \rho$ where n is an integer and ρ is a residual. After successive substitutions and using the results just derived, we obtain,

$$V_A(D;\theta) = \gamma \sum_{i=1}^{n+1} \left(\frac{\theta}{\theta+r}\right)^i + \mu \sum_{i=1}^{n} \left(\frac{\theta}{\theta+r}\right)^i + \left(\frac{\theta}{\theta+r}\right)^{n+1} \left[\rho + V_A(D^*(\theta);\theta)\right], \tag{11}$$

which after simplification yields the desired equation. ■

The properties of $V(D;\theta)$, for $D > D^*(\theta)$, are summarized in the following proposition:

Proposition 2 *For $D > D^*(\theta)$, V is increasing and concave in D and approaches $\frac{\theta(\gamma+\mu)}{r}$ as D approaches infinity.*

Proof. to be written (trivial) ■

Figure 3 depicts the function $V(D;\theta)$ for two different values of ability θ. Notice that $V(D;\theta)$ lies on the 45^o line until $D = D^*(\theta)$ and then becomes flatter and flatter while approaching the mentioned asymptote. In addition, V is piecewise linear in D for $D > D^*(\theta)$, with kinks at each value of D satisfying $D = D^*(\theta) + i\mu$, $i = 1, 2, \ldots, \infty$.

[Figure 3 here]

We now provide some intuition for the function $V_A(D;\theta)$'s behavior. When the debt level satisfies $D < D^*(\theta)$, any auctioneer is willing to take on the boat-owner as a new client offering her an additional loan of $D^*(\theta) - D$ and settling her previous debt by paying D to the previous auctioneer. One can thus re-interpret the function $V_A(D;\theta)$ as the price that a new auctioneer has to pay the previous one for a client (boat-owner) that had an outstanding debt of D and ability θ. Thus, as long as $D \le D^*(\theta)$, any auctioneer can "sell" the boat-owner at no loss, obtaining precisely the current debt level. However, when $D > D^*(\theta)$, we have that the function $V_A(D;\theta)$ is lower than the debt level D. There is a sense in which the boat-owner B is over-indebted, and so if the auctioneer A wanted to terminate the relationship with the boat-owner by selling her to another auctioneer, he would do it at the loss of $D - V_A(D;\theta)$. In addition, the boat-owner would not obtain any additional loan from the new auctioneer. The boat-owner will not obtain any further loan until her debt is reduced to a level lower than $D^*(\theta)$. The term $\frac{\theta}{r}\mu\left(1-\left(\frac{\theta}{r+\theta}\right)^n\right)$ is precisely the expected value of receiving a payoff of μ on each of the next n successful days needed to reduce the debt to $D^*(\theta)$. The term involving ρ is a remainder resulting from the discrete nature of debt repayment process.

Analogously, we can derive the utility stream $V_B(D;\theta)$ that a boat-owner with ability θ and outstanding debt D obtains from her relationship with the auctioneer. We assume that she is an income maximizer and discounts the future at rate $\frac{1}{1+r}$.

$$\begin{aligned} V_B(D;\theta) &= x + \frac{1}{1+r}\left[\theta\left(1-\gamma-\mu+V_B(D-\mu+x;\theta)\right)+(1-\theta)V_B(D+x;\theta)\right] \\ &\quad \text{where} \quad x = \max\{D^*(\theta)-D, 0\} \end{aligned} \tag{12}$$

An important property of the function $V_B(D;\theta)$ is given in the proposition below.

Proposition 3 *The function $V_B(D;\theta)$ is non-decreasing in x.*

Proof. From Equation (12) we obtain the following:

$$\frac{dV_B(D;\theta)}{dx} = 1 + \frac{1}{1+r}\left[\theta\frac{dV_B(D-\mu+x;\theta)}{dD}+(1-\theta)\frac{dV_B(D+x;\theta)}{dD}\right].$$

Since $\left|\frac{dV_B(D;\theta)}{dD}\right| \leq 1, \forall D$, we obtain the desired result. ■

Intuitively, then, the boat-owner will always accept any additional loan that the auctioneer is willing to make.

It is clear that the total surplus from the relationship is $V_A(D;\theta)+V_B(D;\theta)=\frac{\theta}{r}$ thus $V_B(D;\theta)$ has the opposite shape of $V_A(D;\theta)$. Figure 4 depicts both functions for a given ability level θ.

[Figure 4 here]

In summary, the full-information model's main result is that each auctioneer should always earn a zero profit rate independent of the level of debt. Thus, while the profitabilities should equal the opportunity cost of funds, the debt levels will be different, tracking the underlying distribution of ability θ in the population.

4.2 Learning Case

We now enrich the model by assuming that each boat-owner's ability is initially unknown but that villagers share a prior on its distribution. Such a prior may be derived from a boat-owner's success with the previous technology, which, given the size of our study village, can be assumed to be public knowledge. This prior is updated each day the boat-owner goes fishing: each successful catch improves the beliefs about his ability while each unsuccessful day worsens them. Assuming information-efficient individuals, we adopt the method of Bayesian updating. For ease of exposition, focus on the case where the prior belongs to the Beta family of distributions with probability density function given by:

$$f(\theta;\alpha,\beta) = \frac{\theta^{\alpha-1}(1-\theta)^{\beta-1}}{B(\alpha,\beta)}, \tag{13}$$

where $\alpha, \beta \geq 1$ and $B(\cdot,\cdot)$ denotes the Beta function. It is well known that this is a conjugate family of distributions for a stochastic process that obeys a Bernoulli law. If α_t and β_t characterize the posterior after t days of fishing, then the posterior after fishing on day $t+1$ is characterized by $\alpha_{t+1} = \alpha_t + 1$ and $\beta_{t+1} = \beta_t$ if fishing on day $t+1$ is successful and $\alpha_{t+1} = \alpha_t$ and $\beta_{t+1} = \beta_t + 1$ otherwise.

In this case, both $D^*(\cdot)$ and $V_i(\cdot), i = A, B$ become functions of current debt D, α and β, which cannot be solved analytically. Generalizing Equation 5, we can write,

$$\begin{aligned} V_A(D;\alpha,\beta) &= -x + \frac{1}{1+r}\left[\frac{\alpha}{\alpha+\beta}\left(\gamma + \mu + V_A(D-\mu+x;\alpha+1,\beta)\right)\right. \\ &\quad \left. + \frac{\beta}{\alpha+\beta}V_A(D+x;\alpha,\beta+1)\right] \\ &\quad \text{where} \quad x = \max\{D^*(\alpha,\beta) - D, 0\} \end{aligned} \tag{14}$$

In addition, we can derive the optimal debt level $D^*(\alpha,\beta)$ by using the analog expression derived in the previous section where $V_A(D^*(\theta);\theta) = D^*(\theta)$. Using this fact in Equation 14, we obtain

$$D^*(\alpha,\beta) = \frac{\hat{\theta}\gamma + (1-\hat{\theta})P(D^*(\alpha,\beta),\alpha,\beta+1)}{1-\hat{\theta}+r}, \tag{15}$$

where $\hat{\theta} = \frac{\alpha}{(\alpha+\beta)}$. Due to the recursive nature of the function $V_A(D;\alpha,\beta)$ and the optimal debt level $D^*(\alpha,\beta)$ we will state without proving the analog of Proposition **??**.

Proposition 4 *The function $V_A(D;\alpha,\beta)$ and the optimal debt level $D^*(\alpha,\beta)$ has the following properties:*

a) $V_A(D;\alpha,\beta) = D$ *for* $D \leq D^*(\alpha,\beta)$.

b) For debt values $D > D^*(\theta)$*, the function* $V_A(D;\alpha,\beta)$ *is increasing and concave in* D *and approaches the asymptote* $\frac{\alpha(\gamma+\mu)}{r(\alpha+\beta)}$ *as* D *approaches infinity.*

c) The optimal debt value $D^*(\alpha,\beta)$ *(the function* $V_A(D;\alpha,\beta)$*) is increasing (non-decreasing) in* α *and decreasing (non-increasing) in* β*.*

d)The optimal debt value $D^*(t\theta, t(1-\theta))$ *(the function* $V_A(D;t\theta,t(1-\theta))$*) is strictly increasing in* t *and converges to the Full-information value of* $D^*(\theta)$ *(*$V_A(D;\theta)$*).*

Proposition 4 illustrates that, for small and very large debt levels D, the V_A-functions in the learning and full information case coincide. The more interesting dynamics are observed in the optimal debt level D^*, which, for the same value of inferred ability $\hat{\theta}$, rises as the inferential process evolves. The intuition for this result is as follows. The auctioneer benefits for a limited time from a boat-owner with ability higher than the inferred level of $\hat{\theta}$, because due to perfect competition, the boat-owner B can always ask for additional credit if his market value is larger than the current level of debt with auctioneer A. On the other hand, however, if the boat-owner B's true ability is lower than the inferred level $\hat{\theta}$, auctioneer A can only "sell" boat-owner B at a loss due to the less frequent successes for several periods. Therefore, the negative implications of a lower-than-expected type are much more severe than the benefits from a higher-than-expected type and so auctioneers will be overly cautious when extending credit.

5 Testable implications

The model developed in the previous section delivers very clear predictions on the behavior of profitabilities and debt levels over time under the two different cases. This section formally tests these theoretical predictions with the data[7].

The predictions of the model are summarized as follows:

[7]We drop all boat-owners who were financed through the German charitable organization because the motives for the purchase of the boats were not of an economic nature. This charitable organization has the objective to help poor and marginalized villagers.

- **Full Information Case**

  The optimal debt level$D^*(\theta)$ in the case where the ability θ is known, is given by

$$D^*(\theta) = \frac{\theta\gamma}{r} \quad \text{or} \quad r = \frac{\theta\gamma}{D^*(\theta)}. \tag{16}$$

  Therefore,

  (a) Perfect competition drives the profit rate of each auctioneer to the (equal) opportunity cost of funds.

  (b) Debt is proportional to expected sales and thus should be constant over time.

- Learning Case

  (a) The expected profitabilities should *converge to* the opportunity cost of funds in the long-run.

  (b) Debt levels may diverge in the long-run according to the underlying distribution of abilities.

We now take each prediction in turn and test it.

5.1 Initial Profitabilities

The debt balance of fiber boat owners immediately after purchasing the vessel ranges between Rs. 40,000 and 182,000. As mentioned in Section 2, this figure includes pre-existing debt from a kattumaram in most cases.

Figure 5 presents a scatter plot of expected commission revenues from the sales divided by the initial debt balance (the auctioneer's profit rate) against the initial debt balance. Expected sales are computed using actual average sales in the time period between the purchase of the boat and the last day of available data.

[Figure 5 here]

According to the Full Information Case, all points should lie on a horizontal line with the profit rate equal to the auctioneer's opportunity cost r. The mean average profitability in Figure 5 is equal to of a little more than one per mille (or 3.6 percent a month), which roughly corresponds to the opportunity costs of capital cited by one of the auctioneers, who frequently lends from a moneylender at that rate.

However, it is clear that the observations in Figure 5 do not lie on the horizontal line. While a regression line obtained from the 20 data points has no significant slope (T-stat: 1.5), there is considerable dispersion around the mean profitability. Since daily individual sales are stochastic, we test whether the observed dispersion is significantly larger than that implied by the fact that actual sales are noisy. We perform a χ^2 test based on the difference between the actual profitabilities and the mean, and reject the hypothesis that initial profitabilities lie on a horizontal line.

This test can be taken as evidence against the Full Information Case. The variation in the initial debt levels may reflect the different priors that auctioneers have for each boat-owner. The variation in the realized initial profit levels, on the other hand, reflects the fact that the boat-owner's actual ability is not known ex-ante with certainty. The assumption of a profit rate equal to the opportunity cost of capital *on average* is supported by the data and indicates that, at least on average, priors are unbiased.

5.2 Debt Levels and Profitabilities over time

We now turn to the dynamic pattern of debt and profitability for the auctioneer. The data shows that, during the period covered by our sample, debt is renegotiated once for four boat-owners and twice for seven boat-owners. The shortest interval after the initial loan until the first renegotiation is 19 days, while the longest without any renegotiation 345 days. The model developed in Section 4 would predict more renegotiations taking place, however, it abstracts from the possible transaction costs that the auctioneer has to incur to mobilize the funds, or the lumpiness of the expenditures for which the boat-owners use follow-up loans.

The left panel of Figure 6 displays the distribution of initial debt and, for those boat-owners that renegotiated their debt, their new debt level, against the duration of the relationship in days. The solid lines connect observations for a given boat-owner. The right panel depicts the resulting projected profitabilities for the auctioneer computed using the formula in Equation 16. That is, the auctioneer's profitability of having boat-owner i as client with expected daily sales S_{it} and debt D_t at date t, is computed as,

$$r_{it} = \frac{\gamma S_{it}}{D_t}. \tag{17}$$

Expected daily sales are computed using the two methods described above but since again they yield very similar pictures, only the latter approach is reported. It is apparent that the distribution of debt after renegotiation becomes more dispersed while that of profitability becomes more concentrated.

[Figure 6 here]

To prove this last point somewhat more formally, we compute the average square deviations from the overall mean. Notice that while at day zero one has many observations and thus the variance is effectively computed, there may be only one observation in other periods[8]. The model in Section 4.2 where the boat-owner's ability is inferred from the history of catches predicts that the profitability should converge in the long run to the opportunity cost of funds. Therefore, the variance of the profitability should decline over time. Figure 7 displays the average squared differences of debt and profitability over time along with the regression line. Table 3 reports the regression coefficients.

[Figure 7 here]

It is clear that while the debt squared differences do not decline, profitability squared differences decline at a 10 percent significance level[9].

Therefore, the trends in Figure 6 are clearly in line with the dynamic predictions of the learning model, where, no matter what the initial debt and profitability, they approach the opportunity cost of capital in the long run. The growing dispersion in debt levels is also in line with the predictions of the model, where, even for a given common prior and thus identical initial debt, long-run debt levels may approach different values according to the underlying distribution of abilities.

6 Conclusion

This paper explores the behavior of an indigenous interlinked arrangement between the owners of fishing boats and the agents that market their catches and give credit to finance a capital-intensive new technology. We show that at the time of the technology adoption, there is uncertainty about the boat-owner's ability to handle the new technology and

[8] One could separate the observations into bins and compute the variance in each bin. However, lack of data makes such a task impossible.

[9] The standard errors are corrected for the fact that profitabilities are estimated.

Table 3: Squared Differences Regressions

	Debt[a]	T-Stat	Profitability	T-stat
Days	2,293 (1,895)	1.21	-0.00106 (0.00054)	-1.96
Constant	674,000 (395,000)	1.71	0.44310 (0.15379)	2.88
R^2	0.0548		0.2027	
N. Obs	17		17	

SE in parenthesis.

[a] The Debt coefficients are expressed in 1,000 Rs.

that this affects the borrower-lender relationship. We present a model that explains the the diversity of debt values and auctioneer's profitabilities at any point in time. As the true ability of boat-owners is inferred over time, debt levels are adjusted accordingly and profitabilities tend to converge to the opportunity cost of funds. This is precisely what the data shows: the variance of observed profitabilities decrease over time as they cluster around the unconditional mean, equal to the opportunity cost of funds.

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A Figures

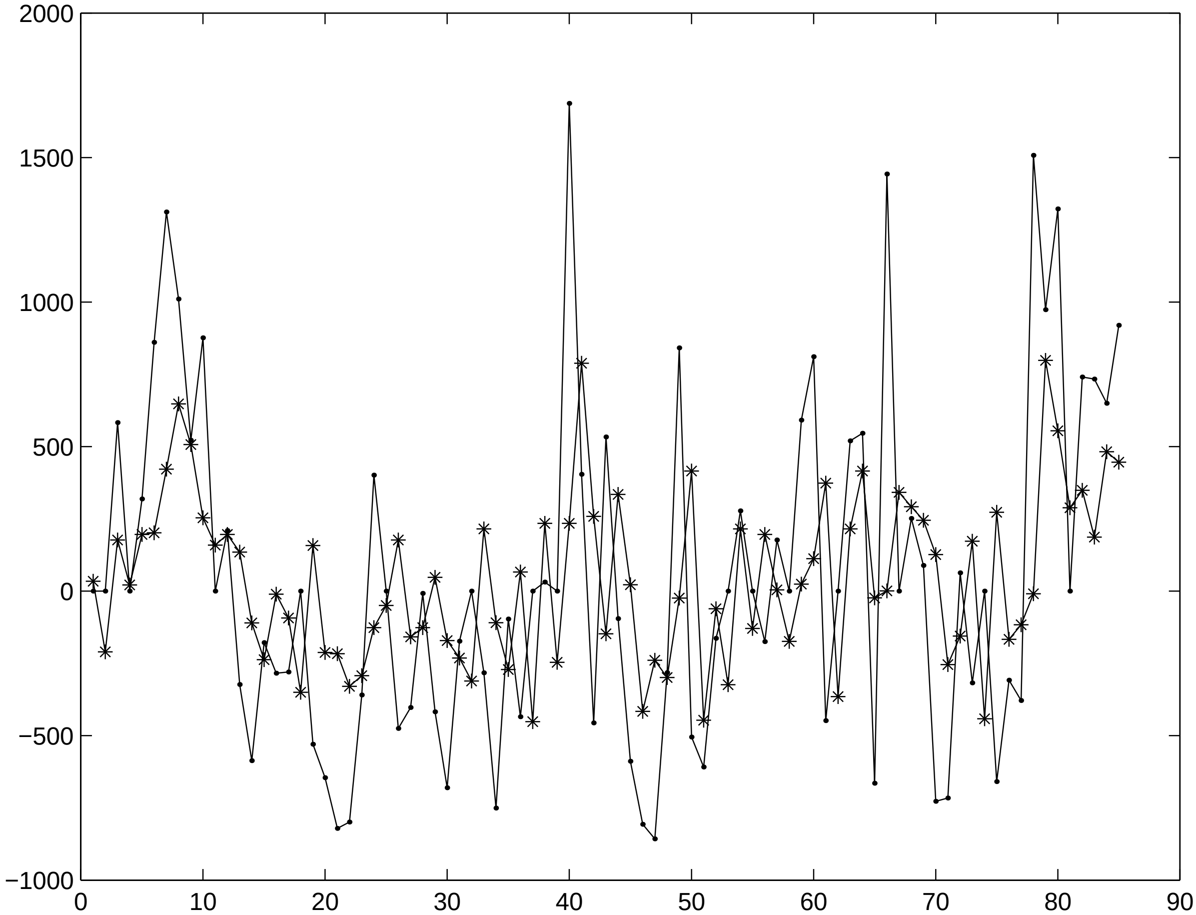

Figure 2: Estimated (dots) and Fitted (stars) aggregate shock.

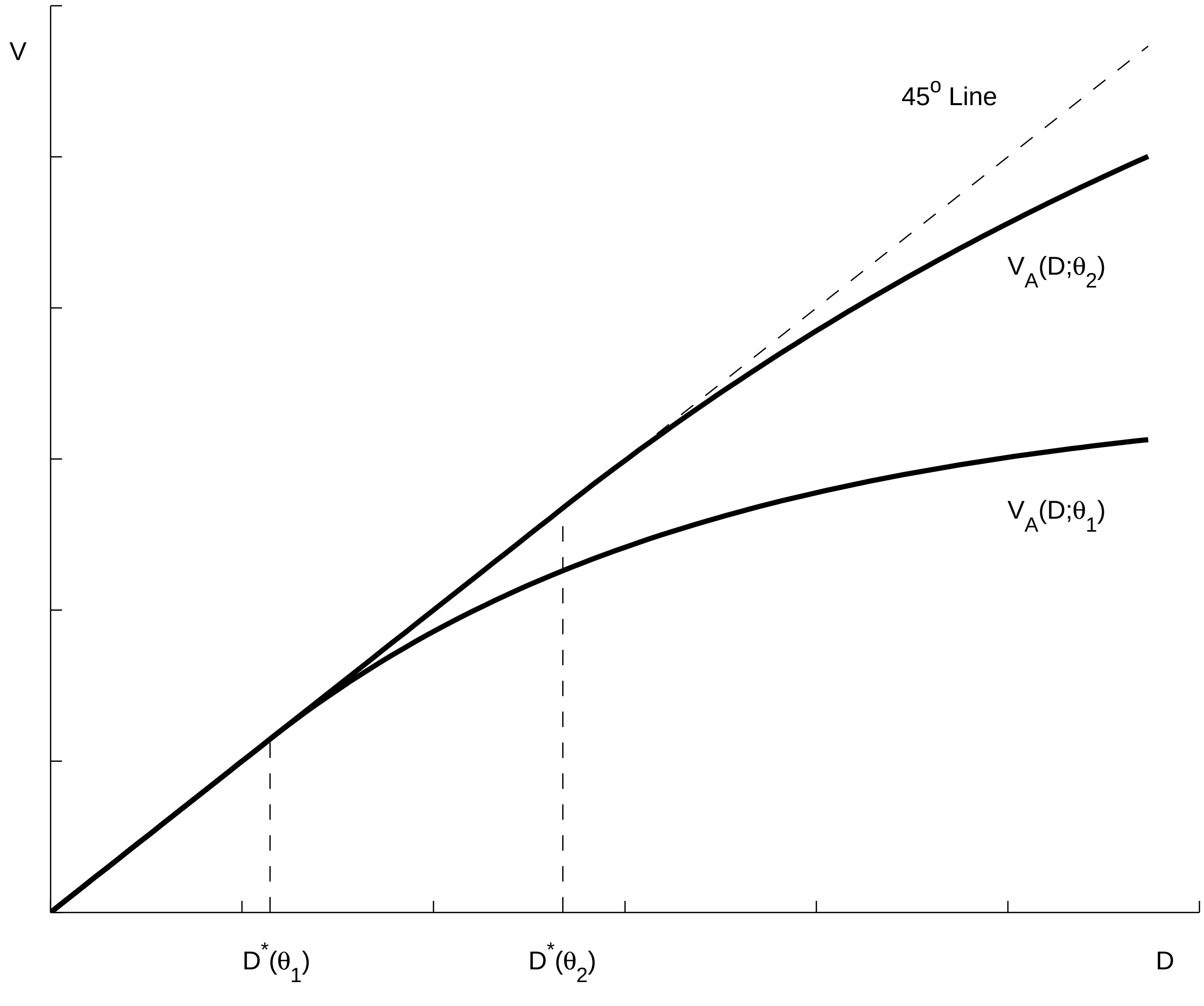

Figure 3: $V_A(D;\theta)$ vs. debt D.

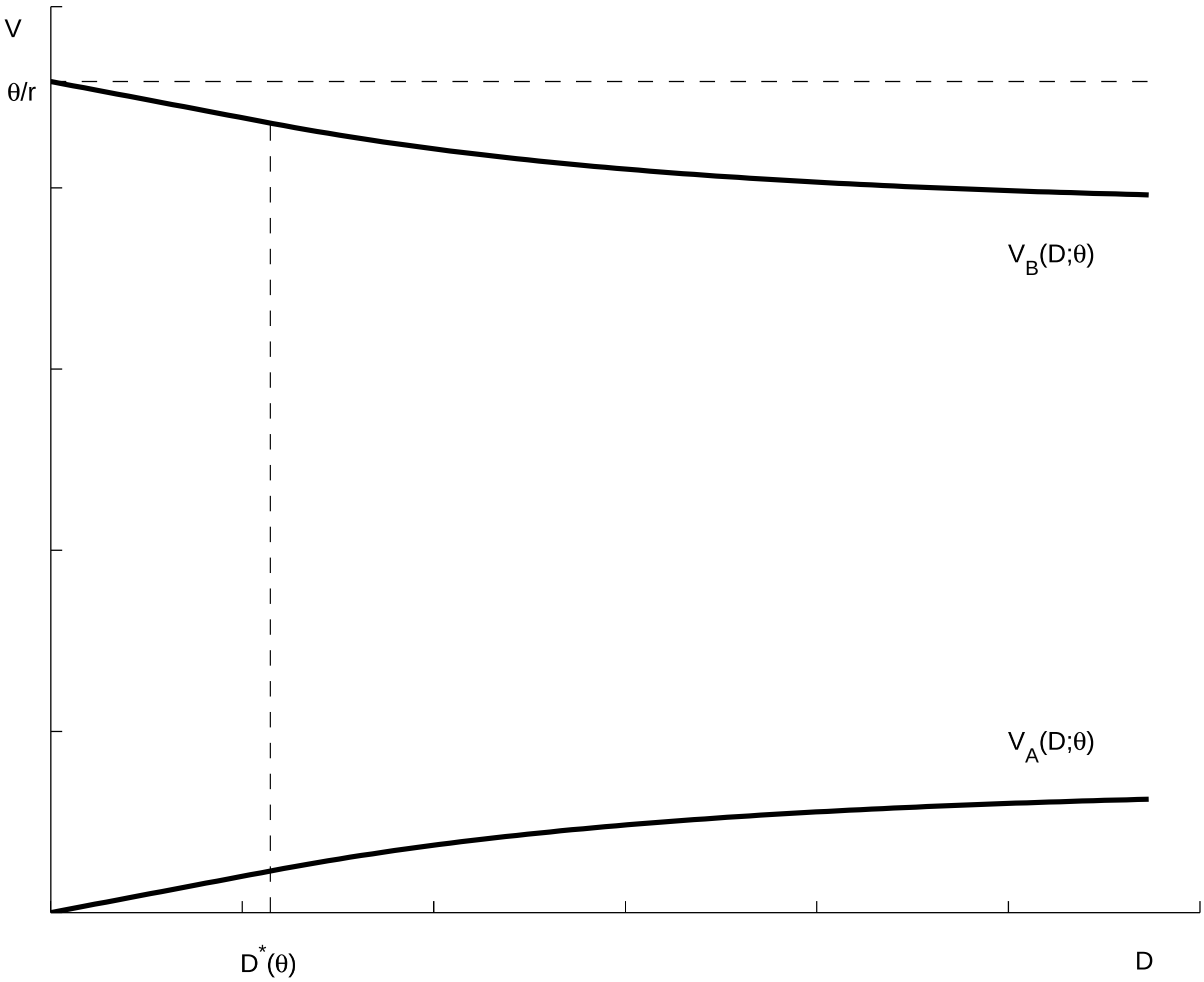

Figure 4: $V_A(D;\theta)$ and $V_B(D;\theta)$ vs. debt D.

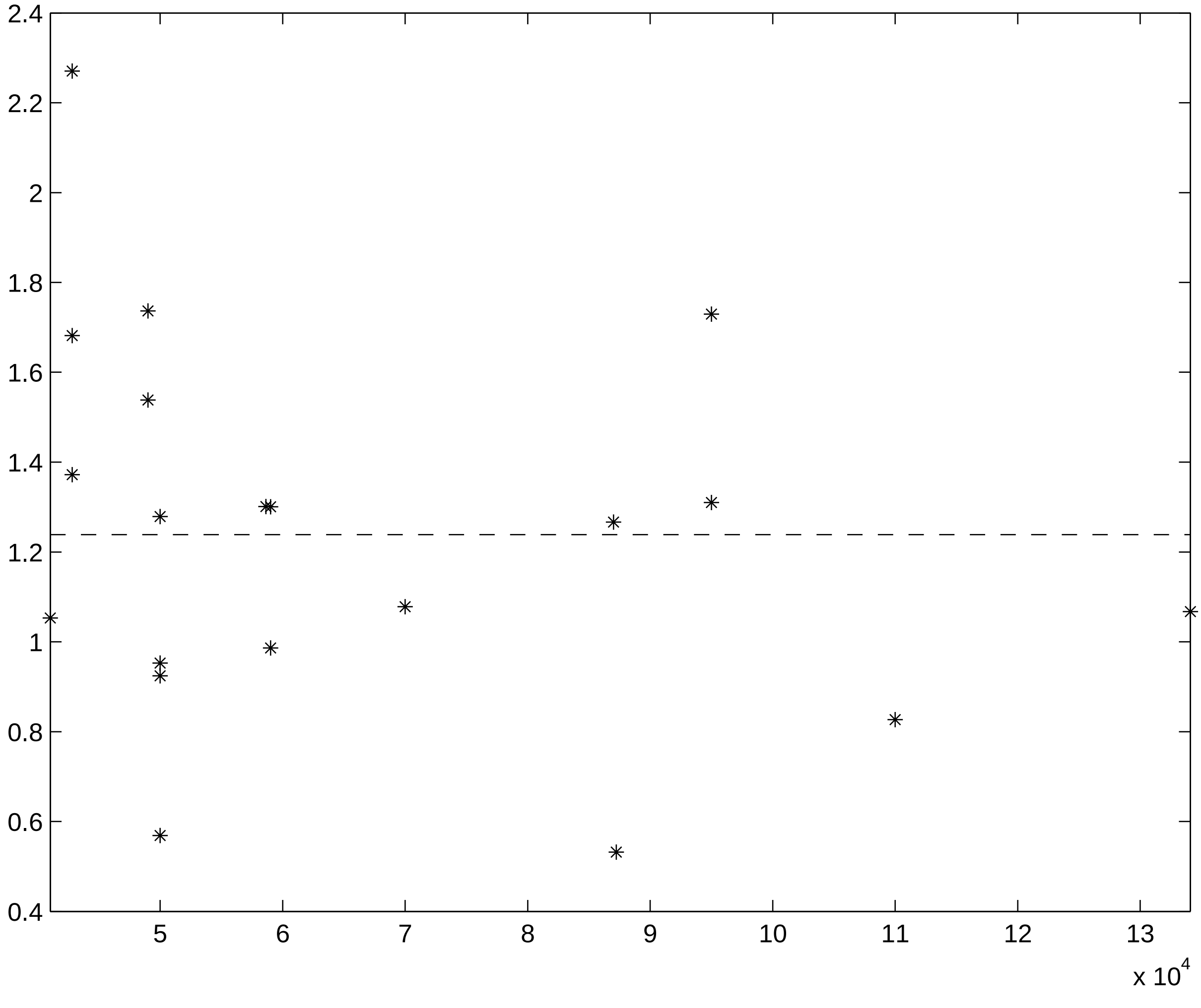

Figure 5: Initial Profitability per mille

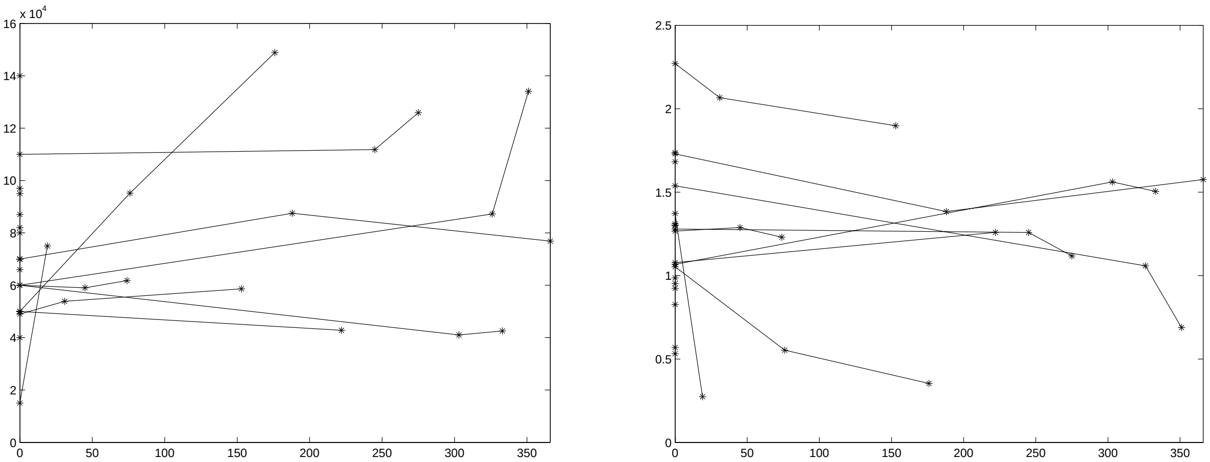

Figure 6: Debt and Profitability over time.

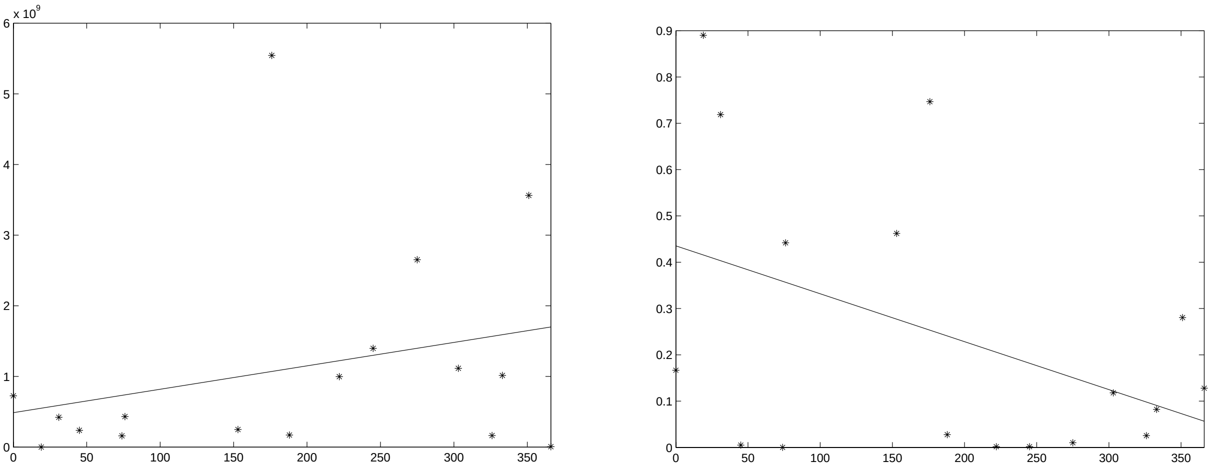

Figure 7: Debt (left) and Profitability (right) average squared differences over time.