INDIVIDUAL TRANSFERABLE QUOTAS IN A HOUSEHOLD ECONOMY: WILL THE SYSTEM WORK?

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ABSTRACT

This paper analyzes the behavior of fishing households under individual transferable quotas (ITQ) system based on Singh, Squire and Strauss household model. ITQ systems are thought to be the optimal fishery management regime in terms of economic efficiency. However, preceding theoretical analyses only consider implementing ITQ in a well established fisheries industry, in which fishermen are mere producers or employees of the industry. They also implicitly assume that all markets are functioning perfectly. Fisheries in developing countries, with prevailing overexploitation, have a very different picture: fishermen are producers and consumers of their own harvest, and most importantly there are market imperfection everywhere. Hence the question: Is ITQ still the first-best fishery management regime under such conditions? The paper first analyzes when all markets are perfect as a benchmark. It is shown that ITQs perform as predicted by the literature; the social optimum is achieved. Throughout this paper, markets for fish and quotas are assumed to be perfect. Next the paper analyzes the effect of missing labor markets to illustrate the consequences of ITQ under market imperfection. It analytically shows that ITQ achieving social optimum is no longer guaranteed, and it may not be the first-best regime either. To demonstrate these points, numerical simulations were carried out. Simulations showed that under certain condition, transfer of quotas could be reversed, i.e. from more efficient to less efficient fisherman. It also showed that transferability could do more harm than good in terms of social welfare.

Keywords: individual transferable quotas; missing market; household model

INTRODUCTION

Individual transferable quotas (henceforth ITQs) system is a management scheme for fisheries based on the property rights and market mechanism. Regulatory authority sets the total harvest as total allowable catch (TAC) and the share of TAC is allocated to each harvester as a quota. In doing so, the ownership of fish to be harvested is effectively privatized, and quotas can be traded among harvesters in the quota market. Theoretically, the price of quota will reflect all or some of externalities caused by the common-pool nature[a] of fishery resources and thus are internalized by harvesters.

ITQs are generally regard in the literature as the optimal fishery management scheme in a sense that it maximizes the rent and require minimum amount of information (Arnason (1990); Batstone and Sharp (2003)). Models used in many of these analyses consider profit maximization as their objective function, where fishermen are mere employees of fishing companies or vessel owners. They implicitly or explicitly assume that surrounding markets are perfect and well-established.[b] Supportive empirical analyses were conducted on ITQs in countries such as Iceland, New Zealand and Australia (e.g. Arnason (1993); Newell, et al. (2002); Pascoe (1993)).

The main question to be addressed in this paper is whether ITQs can be implemented in developing countries, where overexploitation in coastal fisheries is prevalent and an urgent issue (Asian Development Bank (1995)). More specifically, the paper is interested in the effect of ITQs in rural fishing villages of developing countries. One of the distinguished characteristics of such places is that fishing households both sell and consume their harvest. In such case, objective function that households optimize is the utility function, which introduces a potential tension between labor supply and consumption of leisure. Another characteristic is that imperfect markets are common phenomena. There are both theoretical grounds and empirical evidences where households – consuming from their own production – behave differently from being a pure producer (Finkelshtain and Chalfant (1991); Singh, et al. (1986)). In addition, when imperfect markets prevail it is shown that behavior of peasant households are different from what one might expect as rational (de Janvry, et al. (1991)). These features are left out from existing models and analyses in ITQ literature. Yet, this is an important question because developing countries definitely need sound fishery management, and ITQ is regarded as the leading candidate for most efficient management scheme.

MODEL

The model developed in this paper is based on the household model introduced by Singh, et al. (1986). There are three goods in this household model: fish (x_{if}), which a household harvests as production activity and also consumes, leisure (x_{il}) and marketed goods (x_{im}). Marketed goods are essentially everything else that a household consumes other than fish and leisure. Markets for fish, fishing quotas and marketed goods are assumed to be perfect throughout the analyses. Each household has a certain amount of time endowment ($\overline{T}_i$), which it allocates between leisure and labor.

Other usual assumptions are employed in our model. Utility function (u_i) is concave in all goods, twice differentiable and monotonic. Harvest function (h_i) is consisted of two inputs: labor (L_i) and capital, but the level of capital input is assumed to be fixed ($\overline{K}_i$).[c] It is also concave in labor input and twice differentiable. Finally, we assume that initial quotas were granted at no cost to each fishing household.

Perfect markets

All prices are fixed and exogenous for all households. The maximization problem of a household *i* can be written as:

$$\max_{x_{if}, x_{im}, x_{il}, L_i, q_i} \quad u_i\left(x_{if}, x_{im}, x_{il}\right)$$

$$\text{s.t.} \quad p_f x_{if} + p_m x_{im} \le p_f h_i\left(L_i, \overline{K}_i\right) - w\left(L_i - F_i\right) - p_q\left[q_i - \overline{q}_i\right]$$

$$h_i\left(\overline{K}_i, L_i\right) \le q_i$$

$$F_i \equiv \overline{T}_i - x_{il}$$

Subscripts *f*, *m*, and *l* denotes fish, market goods and leisure, respectively. p_j is the market price of good *j*; wage rate and quota price are denoted as w and p_q, respectively. $\overline{q}_i$ is initial quotas allocated to a household *i* (exogenous variable), and q_i is the amount of quotas a household *i* possesses after the trade (choice variable).

Solving for first order conditions yields

$$\left(p_f - p_q\right)\frac{\partial h_i}{\partial L_i} = w. \tag{1}$$

This is the traditional optimality condition, namely value of marginal productivity equals marginal cost. From our assumption that labor is the only variable input in the harvest function, following first order condition determines the optimal level of labor input,[d] and hence the optimal level of harvest (h_i^*). If total harvest quota constraint is binding and quota market price is exogenous, then it can be shown that at optimum each household will equate its harvest level and amount of quota it possesses, i.e. $h_i^* = q_i^*$ (see Appendix A for proof). Therefore, optimal level of quotas to possess is also determined by Eq(1).

Eq(1) shows that households with higher productivity should harvest more than households with lower productivity. This is graphically illustrated in Figure 1. Since $q_i^* \neq \overline{q}_i$ in general, optimal harvest levels in accordance with each household's productivity cannot be achieved without trading quotas among fishing households. In another words, tradable quotas system achieves economic efficiency by redistributing quotas from less productive households to more productive households. This result shows that the outcomes predicted by ITQ theory hold true even under the economy where households consume from their own harvest, so long as all markets are perfectly functioning.

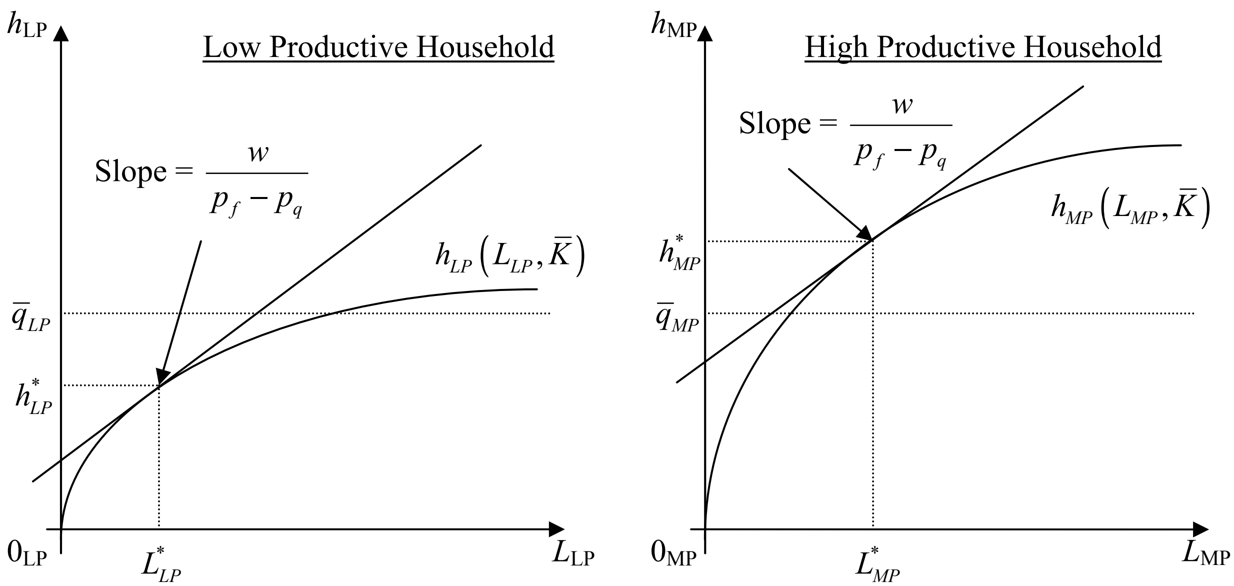

Figure 1. Equilibrium under perfect markets

Missing labor market

To incorporate the missing labor market in our model, we impose a constraint that fishing households can neither hire outside labor nor send their excess family labor to non-fishing jobs. A household could face such a constraint if labor market do not exist, or it exists but a household decided not to participate due to factors such as high transaction cost. The definition of market imperfection is not commodity specific but household specific (de Janvry, et al. (1991)), and therefore the labor market constraint can exist much more common than one might expect.

Under missing labor market, a household i maximize its utility from goods consumption subject to budget constraint, which is determined by its profits from harvest and quota trade, i.e.

$$\max_{x_{if}, x_{im}, x_{il}, L_i, q_i} \quad u_i\left(x_{if}, x_{im}, x_{il}\right) \quad \text{s.t.} \quad p_f x_{if} + p_m x_{im} \leq p_f h_i\left(L_i, \overline{K}_i\right) - p_q\left[q_i - \overline{q}_i\right] \qquad (\lambda_i)$$

$$h_i\left(\overline{K}_i, L_i\right) \leq q_i \qquad (\mu_i)$$

$$L_i = \overline{T}_i - x_{il} \qquad (\gamma_i)$$

Note that labor cost term in the profit equation has dropped out, and all labor input L_i is supplied by family labor. Solving for first order conditions yields

$$\left(p_f - p_q\right)\frac{\partial h_i}{\partial L_i} = \omega_i . \tag{2}$$

ω_i is the value of marginal utility of leisure, γ_i / λ_i, that can be interpreted as household-specific shadow wage. Unlike the case of perfect markets, Eq(2) shows that a household's utility maximization and profit maximization problems are no longer independent. Optimal labor input level and optimal harvest level are determined by the level of ω_i, as Eq(2) shows. Since labor market does not exist, the level of labor input affects the amount of leisure consumption, which in return affects the level of ω_i, and the whole decision cycle begins again.

With missing labor market, the direction of quota trade is no longer definitive. The level of ω_i can differ among households depending on their preference on leisure and their endowment of time. For example, if less productive household has sufficiently large time endowment relative to productive household, *ceteris paribus*, there is a possibility where quota is traded from productive to less productive household, i.e. adverse redistribution of quotas via market. Figure 2 shows such possible outcome. In the following sections, we will demonstrate the possibility of adverse redistribution of quotas analytically by putting more structure to the model, and also by numerical simulations.

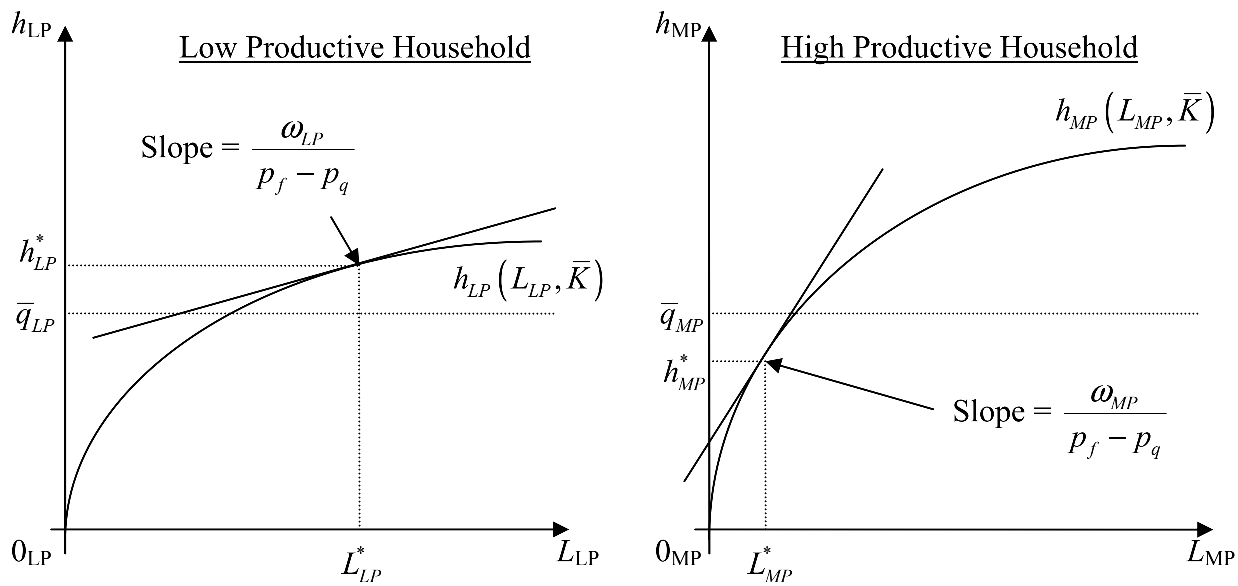

Figure 2. One equilibrium under missing labor market

ANALYTICAL ILLUSTRATION

Let utility and harvest functions be, respectively,

$$u_i = x_{if}^{\beta_f} x_{im}^{\beta_m} x_{il}^{\beta_l}$$

$$h_i = K L_i^{\alpha_i} .$$

Note that capital input is fixed and same for all households. α_i and β 's are parameters between 0 and 1. We assumed that household's preference on each consumptive goods, including leisure, is identical for simplicity. Maximization problem, under the missing labor market, to be solved is thus

$$\max_{x_{if},x_{im},x_{il},L_i,q_i} x_{if}^{\beta_f} x_{im}^{\beta_m} x_{il}^{\beta_l} \quad \text{s.t.} \quad p_f x_{if} + p_m x_{im} \le p_f K L_i^{\alpha_i} - p_q\left[q_i - \overline{q}_i\right]$$

$$K L_i^{\alpha_i} \le q_i$$

$$L_i = \overline{T}_i - x_{il}$$

Solving the first order conditions yield following equations on optimal labor input and leisure consumption

$$L_i^* = \left[\frac{\alpha_i K\left(p_f - p_q\right)}{\omega_i}\right]^{\frac{1}{1-\alpha_i}} \tag{3}$$

$$x_{il}^* = \frac{\beta_l}{\left(\beta_f + \beta_m\right)\omega_i}\left[K\left[\frac{\alpha_i K\left(p_f - p_q\right)}{\omega_i}\right]^{\frac{\alpha_i}{1-\alpha_i}}\left(p_f - p_q\right) + p\overline{q}_i\right]. \tag{4}$$

Assume that time constraint $L_i^* = \overline{T}_i - x_{il}^*$ is binding. Substitute equations (3) and (4) into the time constraint equation and rearrange to yield:

$$\overline{T}_i - L_i^*\left(\omega_i\right) - \frac{\beta_l}{\left(\beta_f + \beta_m\right)\omega_i}\left[K L_i^*\left(\omega_i\right)^{\alpha_i}\left(p_f - p_q\right) + p\overline{q}_i\right] = 0 \tag{5}$$

Since we assumed that all households' preference on leisure is identical, we will focus on the heterogeneity of time endowment as a factor that affects the level of shadow wage, ω_i. By applying the Implicit Function Theorem on Eq(5), it can be shown that the shadow wage decreases as time endowment increases and vice versa (i.e. $\partial\omega_i / \partial\overline{T}_i < 0$, see Appendix B). This is an intuitive result; as time endowment increases the tension of time constraint is relaxed, which will decrease the shadow wage via decreasing shadow value of leisure, γ_i.

What can we say about the level of ω_i and whether a household is a net buyer or seller of quotas? If a household is a net buyer of quotas at equilibrium then it must be true that $q_i^* > \overline{q}_i$. Since $h_i^* = q_i^*$ must hold at equilibrium, this implies that

$$h_i^* = K\left[\frac{\alpha_i K\left(p_f - p_q\right)}{\omega_i}\right]^{\frac{\alpha_i}{1-\alpha_i}} > \overline{q}_i .$$

Solving for ω_i yields the following condition for a net quota buying household

$$\omega_i < \alpha_i K\left(p_f - p_q\right)\left(\frac{\overline{q}_i}{K}\right)^{1-\frac{1}{\alpha_i}}. \tag{6}$$

The right-hand side of Eq(6) is consisted only from predetermined and exogenous parameters. Therefore we can conclude the following: for given household's productivity parameter α_i and initial distribution of quotas $\bar{q}_i$, even the less productive household (with small α_i) can be a net quota buyer if time endowment is sufficiently large such that its shadow wage drops below the threshold depicted by Eq(6).

NUMERICAL SIMULATIONS

To illustrate the case where adverse redistribution of quotas under missing labor market occurs, we conducted numerical simulations using GAMS. Harvest (production) function and utility function are the same as those used in analytical illustration. Objective function to be optimized is the social welfare function defined as the sum of individual household's utility. In this simulation we have two households; high productive and low productive household. They are denoted by *MP* and *LP*, respectively. Parameters were specified as in Table I. Note that $\alpha_{MP} > \alpha_{LP}$ must hold to be consistent with our households' productivity assumption.

Table I: Parameter values used in simulations

Parameter	Value	Parameter	Value
α_{MP}	0.50	$\bar{Q}$	75.2
α_{LP}	0.40	$\bar{K}$	10.0
β_f	0.17	p_f	2.0
β_m	0.60	p_m, p_q	1.0
β_l	0.23		

p_f, p_m, p_q : price of fish, marketed goods and quota, respectively
$\bar{Q}$: total amount of quotas $\bar{K}$: fixed capital input

Total amount of quotas, $\bar{Q}$, is set such that it will not be a binding constraint for these two households. This is to make simulations consistent with the analytical model, where unit price of quota, p_q, was exogenous and held constant. Any amount of quota surplus will be absorbed by someone outside of simulated world.[e]

As pointed out in the conceptual model section, our interest is how the quota trade and the equilibrium level of labor input for harvesting change as the time endowment of *LP* household increases relative to *MP* household. For this simulation, we held $\bar{T}_{MP}$ constant at 15 units[f] while increasing $\bar{T}_{LP}$ from 10 to 110 units. Simulation under perfect markets showed that regardless of the levels of time endowment *MP* household will purchase and *LP* household will sell quotas.

Figure 3 shows the quota trading activities of each household under the missing labor market condition. Vertical axis measures the amount of quotas sold by each household. First result is that if $\bar{T}_{MP}$ is sufficiently low the *MP* household would sell its initially allotted quotas rather than purchasing them. This is a straightforward result; being unable to hire labor from outside its own household and demand for leisure in presence, the optimum is to harvest at lower level and sell its excess quotas.

Second result that can be seen in Figure 3 is that *LP* household goes through a transition from quota seller to quota buyer as its time endowment level rises. Since family labor cannot be hired out, it must be allocated between harvesting and leisure. Due to diminishing marginal utility of leisure so much time can be allotted for leisure and the rest will be put into labor for harvesting. When time endowment is sufficiently high *LP* household will expand its harvest beyond the initially allotted quotas, and thus buys additional quotas from the market.

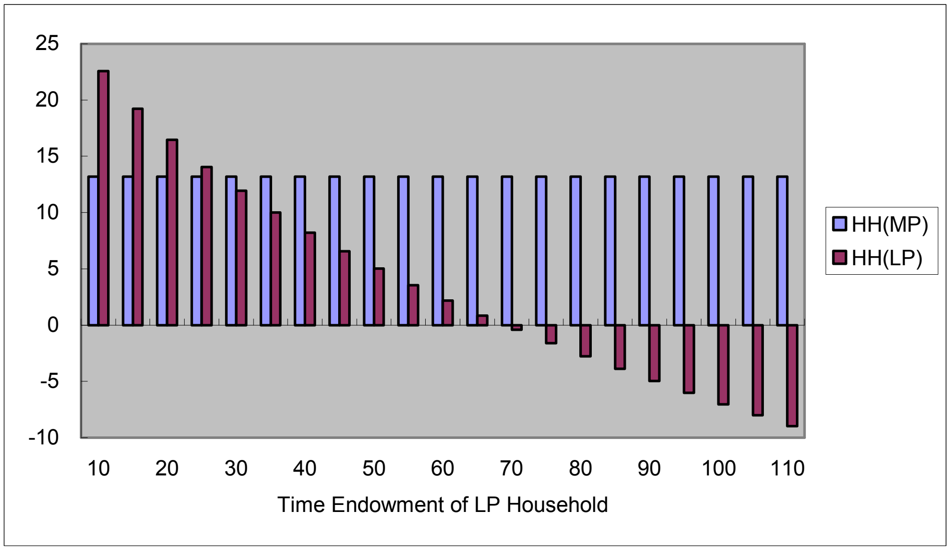

Figure 3. Quota trading activities of each household

We know that individual households should not trade their quotas unless there is a benefit to do so. Our simulation verified that trading quotas actually achieved higher or at least the same level of utility in each household for all cases, even when quotas were adversely redistributed. Figure 4 shows the utility difference between "with" and "without" quota trade. The gain for *MP* household is constant, while that of *LP* household first decreases but then rises again as its time endowment increases. Line graph is the difference in social welfare, and it shows that quota trade enhances social welfare of the two households.

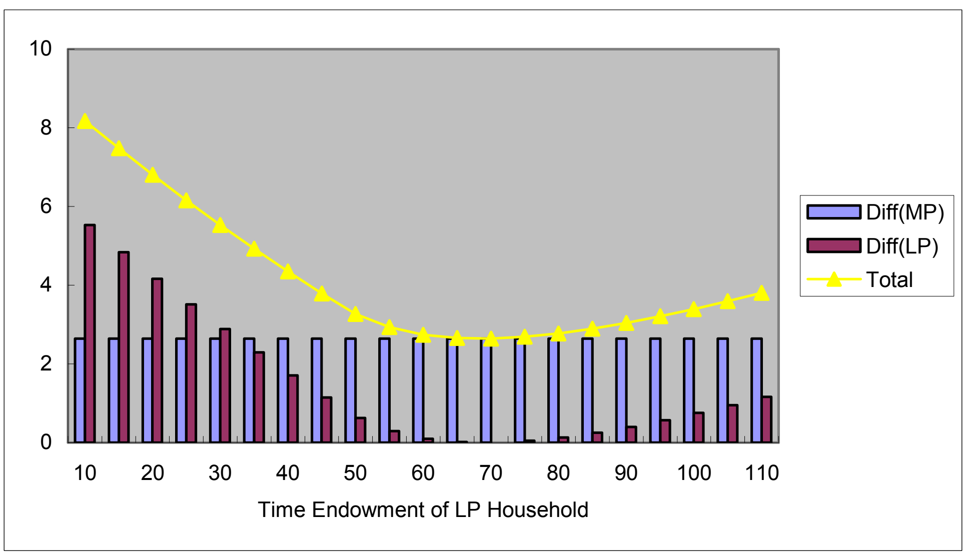

Figure 4. Welfare gains from quota trade

At this juncture, it seems that allowing transferability of quotas is preferred over restricting it, despite the fact that it induces adverse redistribution of quotas. As long as these two households are concerned, this is a true statement. It may not be true, however, if we consider the impact of quota transferability might have outside of these households. One possibility is waste of resource. Intuitively, since high productive household is lowering its harvest level while low productive household is expanding, one would expect that there is a waste of labor input as a result of quota transferability.

Figure 5 depicts that waste of labor is present for certain combination of time endowment levels. Harvest-labor ratio (measured in vertical axis) with quota trade (solid line) drops below that of without quota trade (dotted line) when time endowment for *LP* household is sufficiently larger than that of *MP* household. This implies that with quota trade more labor is put into harvesting than it would take to realize the same amount of harvest had quotas were not traded. However, as long as trading quotas is allowed each household would trade their quotas, despite of overall waste of labor.[g] This occurs because each household is better off to do so, as shown in Figure 4.

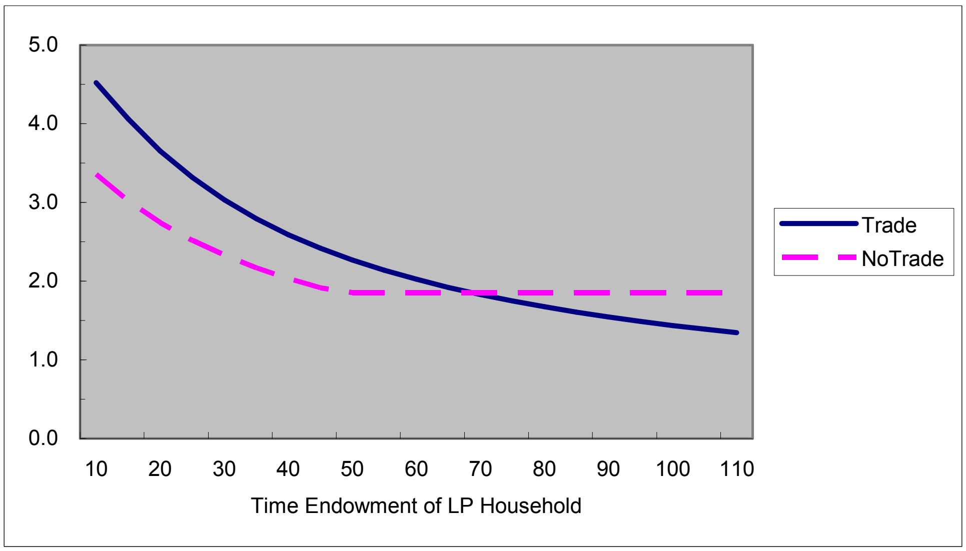

Figure 5. Harvest-labor input ratio comparison between with and without quota trade

CONCLUSION

Using a simple household model we have shown that, under certain conditions, with missing labor market ITQ system could transfer more quotas to less productive household and fewer quotas to more productive household. This is a unique phenomenon owing to the existence of missing labor market in the context of household economy; conditions typically seen in rural coastal villages in developing countries.

The model implies that the occurrence of such adverse redistribution of quotas is one of the possibilities when ITQ system is implemented under market imperfection. Whether or not it actually occurs is an empirical issue. The implication of this paper is that, because there is this possibility of adverse redistribution of quotas, ITQ system is not always the best fishery management scheme. When the existence of market imperfection is suspected a careful assessment of the consequences of implementing the ITQ system is critical, and in some cases alternative management regimes may need to be considered.

APPENDIX A

Proof of "*If total amount of quota constraint is binding then at optimum each household will equate its harvest level and amount of quota it possesses*."

Lagrangian can be written as:

$$u_i\left(x_{if}, x_{im}, x_{il}\right) - \lambda_i\left[p_f x_{if} + p_m x_{im} - p_f h_i\left(L_i, \bar{K}_i\right) + p_q\left(q_i - \bar{q}_i\right)\right]$$
$$- \mu_i\left[h_i\left(L_i, \bar{K}_i\right) - q_i\right] - \gamma_i\left(L_i - \bar{T}_i + x_{il}\right)$$

Relevant Kuhn-Tucker first order necessary conditions are:

$$q_i: \qquad p_q = \frac{\mu_i}{\lambda_i} \tag{A1}$$

$$\mu_i: \qquad h_i\left(L_i, \bar{K}_i\right) - q_i \le 0, \qquad \mu_i\left[h_i\left(L_i, \bar{K}_i\right) - q_i\right] = 0 \tag{A2}$$

If each household does not equate its harvest level and amount of quota it possesses at optimum, i.e. $h_i^* < q_i$ for all *i*, then (A2) implies that $\mu_i = 0$, which then leads to $p_q = 0$ from (A1).

This will occur if the total quota constraint is not bonding, i.e. $\sum_i \tilde{h}_i < \sum_i \bar{q}_i \equiv \bar{Q}$, where $\tilde{h}_i$ is the optimal harvest level of household *i* before the introduction of quotas. Therefore, if the total quota constraint is binding then $p_q > 0$, which implies $\mu_i > 0$ from (A1) and $h_i^* = q_i$ for all *i* from (A2).

Q.E.D.

APPENDIX B

Define Eq(5) as

$$\Phi \overset{def}{=} \bar{T}_i - L_i^*\left(\omega_i\right) - \frac{\beta_l}{\left(\beta_f + \beta_m\right)\omega_i}\left[KL_i^*\left(\omega_i\right)^{\alpha_i}\left(p_f - p_q\right) + p\bar{q}_i\right]. \tag{B1}$$

Comparative static of ω_i with respect to $\bar{T}_i$ can be derived from Implicit Function Theorem as

$$\frac{\partial \omega_i}{\partial \bar{T}_i} = -\frac{\partial \Phi / \partial \bar{T}_i}{\partial \Phi / \partial \omega_i}. \tag{B2}$$

Since $\partial \Phi / \partial \bar{T}_i = 1$, the sign of $\partial \omega_i / \partial \bar{T}_i$ depends on the sign of $\partial \Phi / \partial \omega_i$. Using equation (B1), this derivative is

$$\frac{\partial \Phi}{\partial \omega_i} = -\frac{\partial L_i^*\left(\omega_i\right)}{\partial \omega_i} + \frac{\beta_l}{\left(\beta_f + \beta_m\right)\omega_i^2}\left[KL_i^*\left(\omega_i\right)^{\alpha_i}\left(p_f - p_q\right) + p_q\bar{q}\right]$$
$$- \frac{\beta_l}{\left(\beta_f + \beta_m\right)\omega_i} K\alpha_i L^*\left(\omega_i\right)^{\alpha_i - 1}\frac{\partial L_i^*\left(\omega_i\right)}{\partial \omega_i}\left(p_f - p_q\right) \tag{B3}$$

To sign this derivative, we need to know the sign of $\partial L_i^*\left(\omega_i\right) / \partial \omega_i$. From Eq(3), it can be shown that

$$\frac{\partial L_i^*\left(\omega_i\right)}{\partial \omega_i} = -\frac{1}{1-\alpha_i}\left[\frac{\alpha_i K\left(p_f - p_q\right)}{\omega_i}\right]^{\frac{\alpha_i}{1-\alpha_i}}\left[\frac{\alpha_i K\left(p_f - p_q\right)}{\omega_i^2}\right] < 0 \qquad \text{(B4)}$$

Recall that $p_f - p_q > 0$ is assumed. From Eq(B3) the result of Eq(B4) implies $\partial\Phi / \partial\omega_i > 0$. Therefore, from Eq(B2) we can conclude that $\partial\omega_i / \partial\overline{T}_i < 0$.

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ENDNOTES

[a] "[E]verybody's property is nobody's property." Gordon (1954), p.135.

[b] Presence of market power in the output market (i.e. fish market) and quota market has been considered (e.g. Anderson (1991; Malik (2002)).

[c] In the context of fisherman household in a developing country, it is plausible to assume that capital inputs, such as boats and gears, are fixed in the short-run.

[d] We assume $p_f > p_q$ throughout. If $p_f \leq p_q$ then every household will find profitable (or indifferent if equality holds) to sell off their quota rather than harvesting, and hence there would be no fishing activities.

[e] Note that this is not to say that $\bar{Q}$ is *overall* not binding. The simulation model assumes that there is enough number of other fishery participants whom the two households can purchase or sell quotas. Recall that if overall $\bar{Q}$ is not binding then the quota price must equal to zero (see Appendix A).

[f] This figure was chosen based on that, under the perfect market condition, *MP* household needs 12.3 units of labor (family + hired) to harvest initially allotted 37.6 units of fish.

[g] It could be argued that the labor is not wasted *per se*, as they would otherwise be idle due to missing labor market. However, in practice more labor requires more of other variable inputs, such as gasoline to operate their boats and more air and sea pollution that could arise from it. In other words, the term "labor" can be interpreted here as a representation of other harvest-related variable inputs.