Property Rights, Uncertainty and Option Value

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Abstract:
This paper addresses resource valuation and the harvest decision of the firm under uncertain property rights. The results are extended to a market model. The observations suggest that policies addressing externalities resulting from poorly defined property rights need to consider interest rates and price effects in structuring resource rights.

Property rights definitions improve as markets for natural resources such as air and water develop. This evolution of property rights facilitates exclusivity, trade and enforceability (Teitenberg, 1996). Markets and trade give rise to questions about resource value. Buying the right to pollute, to burn rice fields, to harvest fish, or use in-stream water rights are examples of buying an option to utilize a resource.

Option value is often used in the resource literature. This concept is developed in both the natural resource and finance literature. With respect to resources, the concept has been developed along two lines. One is based on consumer theory and deals with existence value and certainty equivalence measures. Although work on this area proliferated through the 1980's, a lack of helpful measures resulted in waning interest. The second form of option value, first developed by Arrow and Fisher (1974) is known as "quasi-option value". This theory developed to include the effects of uncertainty, and the benefit of flexibility on valuing a development decision. A third form of option value exists in the financial literature. In finance, an option represents the right, but not the obligation, to buy or sell a stock at a given future date. This method also incorporates stochastic measures into the valuation of the option. In addition to valuing financial assets, option pricing is applicable to natural resource examples as well. For example, tradable pollution permits, water rights, and fish harvesting rights may all benefit from this technique.

Each of these examples relies on a new specification of property rights to overcome an externality. By specifying property rights, firms internalize the costs of their decisions. The new property rules and cost implications change the investment perspective of the firm. Established valuation rules and techniques illustrate the investment valuation changes necessary under new rights systems. The Arrow and Fisher result illustrates how investment and use patterns must be modified to incorporate uncertainty. Net Present Value (NPV) analysis, a frequently used project valuation method, overlooks uncertainty and results in over-stated project benefits. A benefit of the Black-Scholes option pricing model is that it directly incorporates stochastic elements into a market-based valuation.

However, each of these cases assumes that property rights are well-defined. That is, rights are enforceable and exclusive, and there is no externality present regarding property rights and resource utilization. When well-defined-property rights do not exist, such as in an open access fishery, the incentive is to harvest as much as possible, as quickly as possible. There is no value of waiting.

However, recent fishery management techniques, such as individual fishing quotas (IFQs) represent an improvement in defining property rights. By improving rights, there is an incentive to postpone the harvest decision to maximize net benefits over time. However, these rights are harvesting privileges only. The resource is still not owned until harvested. This paper explores the implication of uncertainty regarding property rights on the investment and resource harvest decision of the firm. The paper examines the benefits and shortcomings of potential valuation mechanisms and presents suggestions for these tools under varying property rights regimes.

The six following sections develop these ideas. Section two provides an introduction to the empirical backdrop for this paper, the North Pacific halibut fishery IFQ program and the property rights issues in this setting. Section three presents the Arrow Fisher results relative to the IFQ fishery. This section clarifies the point that the opportunity cost of foregone future opportunity must be included in today's harvest decision. The existence of property rights introduces a value to waiting. Section four develops a market application via NPV analysis that is developed to demonstrate the value of waiting, and how property rights impact this value. Section five considers the applicability of the Black Scholes option pricing model to IFQ valuation. Noting that ex-vessel fish prices are critical in determining the value of an IFQ within a season, and that harvesters are price takers, a special attention is placed on the optimal allocation of the harvest over the season. Section six considers the market effects of property rights and harvest timing on resource allocation in a two period model. The closing section provides the implications of this study, the conclusions and further areas for study.

2. The North Pacific Halibut Fishery transition to IFQs

In 1995, the National Marine Fisheries Service introduced individual fishing quotas (IFQs) in the North Pacific halibut fishery off Alaska. IFQs are a harvesting privilege to an annually managerially-determined total allowable catch. They represent a radical shift in the management policy from an open access to a rights-based fishery, subject to various restrictions on rights holders. This management transition provides an opportunity to explore the effects of open access versus defined property rights on the resource investment and harvest timing decisions.

This analysis facilitates the exploration of two questions: how do IFQs change the value of entry into the fishery, and, what is the market impact of IFQs with respect to harvest timing.

2.1 IFQs and the value of entry

Prior to the IFQ system, the halibut fishery season was limited to 2, 24-hour seasons in the most extreme cases. The harvest timing for the fishers was simple, harvest during the allotted time period. Since the implementation of IFQ system, the season lasts eight months. Under this scenario,- harvesters must allocate their IFQs(total catch allocation) across this time horizon. This paper's model is based on a two period fishing season. Now the decision is, given an IFQ what is the optimal allocation of q_1 and q_2 between time period one and time period two.

3. Arrow fisher result with respect to IFQs

The Arrow and Fisher(1974) result demonstrates that failure to incorporate uncertainty into the resource use decision results in over-use in the first period. This insight is pertinent to the IFQ valuation and harvest model. Their result, based on the decision to develop a parcel of land, is developed in this section under the fishery scenario.

Arrow and Fisher also show that an irreversible project or decision should include the loss of the option for future use decisions. In the IFQ fishery, fishing today means that one may harvest less, or nothing (up to the IFQ amount) tomorrow. The following example adapts the Arrow Fisher model to an IFQ:

IFQ = total quantity of fish available for harvest

Q_1 = total quantity (pounds) of fish harvested in time 1

Q_2 = total quantity of fish harvested in time 2

π_1 = expected benefits, profits/pound from harvesting, period 1

π_2 = expected benefits, profits/pound from harvesting, period 2

$c_1 = (\pi_2 - \pi_1)$ = opportunity cost of harvesting in period 1

For consistency with Arrow and Fisher's analysis, let

w= $\pi_1 - c_1 = \pi_1 - (\pi_2 - \pi_1)$ =net benefits after opportunity costs in period 1

Let event A be the case where π_2 >0.

If A occurs, then the total benefits (TB(A)) of harvesting are:

$$\pi_1 Q_1 - c_1 Q_1 + \pi_2 (IFQ - Q_1)$$
$$= wQ_1 + \pi_2 (IFQ - Q_1) \equiv TB(A)$$

If A does not occur (π_2 <0), the total benefits (TB(NA)) of harvesting are:

$$\pi_1 Q_1 - (\pi_2 - \pi_1) Q_1 = wQ_1 \equiv TB(NA)$$

If Q_1 >0, the expected benefits from harvesting are:

$$= wQ_1 + \max\left[\pi_2 (IFQ - Q_1),0\right]$$

If Q_1 =0, the expected benefits from harvest are:

$$E\left[\max(\pi_2 IFQ,0)\right]$$

The difference of the expected benefits, when $Q_1 > 0$, versus $Q_1 = 0$ is, H_u, the benefits of the harvest under uncertainty:

$$\begin{aligned}&\mathrm{E}\left[wQ_1 + \max(\pi_2(IFQ - Q_1),0)\right] - \mathrm{E}\left[\max(\pi_2 IFQ,0)\right] = \\ &\mathrm{E}\left[wQ_1 + \min(-\pi_2 Q_{1,0} 0)\right] \equiv H_u\end{aligned}$$

If, instead of uncertainty, we replace w and π_2 with known numbers. Then we have, the expected benefits of harvest under certainty, H_c:

$$\mathrm{E}[w]Q_1 + \min((-\mathrm{E}\pi_2)Q_1,0) \equiv H_c$$

If H_u - $H_c < 0$, this indicates that the stated benefits of harvesting under certainty exceed the benefits of harvesting under uncertainty. In a situation involving uncertainty, such as a fishery where resource levels and market prices are stochastic, over-stating the benefits by assuming certainty in harvest decisions will lead to over harvest in the first period.

Consider the following two cases:

Case I: $0 < -\mathrm{E}(\pi_2) \Rightarrow \pi_2 > 0$

$$\begin{aligned}&\min(-\pi_2 Q_1,0) < 0 \\ &P\left[\min(-\pi_2 Q_1,0) < 0\right] > 0 \\ &\mathrm{E}\left[wQ_1 + \min(-\pi_2 Q_1,0)\right] < 0 \\ &\text{and} \\ &\mathrm{E}\left[wQ_1 + \min(-\pi_2 Q_1,0\right] < \mathrm{E}[w]Q_1 + 0\end{aligned}$$

Case II: $0 > -\mathrm{E}(\pi_2) \Rightarrow -\mathrm{E}(\pi_2) < 0$

Following the same steps as Case I, we get:

$$\mathrm{E}\left[wQ_1 + \min(-\pi Q_1,0)\right] < \mathrm{E}[w]Q_1 - \mathrm{E}\left[\pi_2\right]$$

In each case, replacing uncertainty with certainty overvalues the benefits of harvesting, and promotes over-harvesting in period one.

4. Net Present Value under Uncertainty

Now that we have established that uncertainty must be incorporated into the valuation of harvest to promote optimal allocation, consider the impact of this understanding using a financial tool such as Net Present Value (NPV).

NPV allows us to consider the value of a discounted stream of future cash flows. In this case, it would give the value of an IFQ today based on the expected value of future earnings. However, a short-coming of this method is that it takes future prices as following a known price path.

That is, the NPV of an IFQ in a two period model would be (Dixit and Pindyck, 1994):

$$\mathrm{NPV} = \pi_0 q_0 + \frac{\pi_0(\mathrm{IFQ} - q_0)}{(1+r)}$$

Where, $q_1 = \mathrm{IFQ} - q_0$
$\pi_0 = \mathrm{Profits/lb}$

Next incorporate uncertainty into the valuation, put off harvesting until the next period, and then only harvest if the profits per pound increase. The NPV_u model becomes

$$\mathrm{NPV}_u = \psi(1+u)\pi_0 \frac{(\mathrm{IFQ} - q_0)}{(1+r)}$$

Where,

$\psi =$ the probability that prices rise in the next period

(1+u) = the magnitude of the price rise

The value of waiting is then, NPV_u-NPV, or

$$\underbrace{\pi_0\left[\frac{\mathrm{IFQ}}{(1+r)}(\psi(1+u)-1)\right]}_{A} + \underbrace{q_0}_{B}\frac{r}{(1+r)},$$

which is positive when $\psi(1+u)$ is greater than one.

Now consider the question of property right uncertainty. The most straightforward approach is let ψ equal one, so that profits per pound increase with certainty by (1+u) next period. However, introduce a new factor, γ that denotes the degree of property rights specification. Let $0 \le \gamma \le 1$, such that 0 will denote the open access case, where property rights are absent, and 1 would denote a sole owner, or completely defined property rights.

Now the value of waiting is:

$$\frac{\pi_0(\mathrm{IFQ}-q_0)}{(1+r)}\left[\gamma(1+u)-1\right]-\pi_0 q_0$$

That is, in the open access case, when γ equals 0, the value of waiting is negative. Therefore, it is optimal to harvest everything in the first period.

Now consider a no arbitrage condition. That is $0 \le \gamma \le 1$ and we want to ensure that profits can not be made by disparities between interest rates and price changes. Equate the trade-off between the payoff from harvesting this period with the payoff from harvesting next period:

$$\pi_0 \mathrm{IFQ} = \gamma \frac{(1+u)}{(1+r)} \pi_0 \mathrm{IFQ}$$

when

$$\gamma = \frac{(1+r)}{(1+u)}$$

For example, when $\gamma < 1$, the ex-vessel prices are rising faster than the rate of interest. However, given the uncertainty over property rights, it is sub-optimal to allocate the entire harvest to the next period. This model provides an interesting insight between property rights, interest rates and price rises. It is evident that as the rate of price rises increases, property rights definitions can diminish, ie $\frac{\partial \gamma}{\partial u} < 0$. That is, as prices rise more quickly, even with a low-probability of harvest, it is valuable to wait. Conversely, consider the interest rate effect. $\frac{\partial \gamma}{\partial r} > 0$. This relationship implies that as interest rates rise, property rights must be increasingly well specified to engender harvest postponement.

5. Financial Options, Value and the Harvest Decision

So far, we have introduced the concept that when there is uncertainty surrounding a harvest decision, this uncertainty must be incorporated into the harvest timing model or over-harvest will occur in period one. We added to this story by incorporating uncertainty over property rights. This develops conflicting tendencies: to wait given uncertainty over future market conditions, or to harvest now given uncertainty over future ability to harvest one's catch. The NPV method inappropriately values the option to allocate harvest over time. NPV omits the value of flexibility and waiting for optimal market conditions. The market extension of the Arrow Fisher result is the options market.

Since IFQs are traded assets, options theory provides a helpful starting point for their valuation. Financial options represent the right but not the obligation to buy or sell a stock for a given price in the future. For American options, one may exercise this right at any time up to the option expiry, T (the exercise date) (Wilmott, 1996). However, theory shows that for non-dividend paying stocks, it is optimal to exercise at the last possible time. A simple binomial tree supports this point (Figure 5.1). At time zero, let the stock value equal \$1 (S_0). At time one, it will either go up by a factor of u (u>1) or down by a factor of d (d=1/u<1).

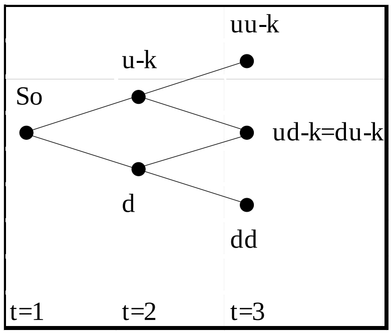

Figure 5.1

Note also that 1/u=d<k<1<u. Since an option is the right to buy the stock in this case, k is the agreed upon price of the stock at the time of purchase. Therefore for $(S\text{-}k)^+$ the option will be exercised. Now we determine the optimal exercise time. In this example, let the interest rate equal r=0, and there are no dividends. The Black Scholes formula relies on a Qmartingale to form the valuation (see Wilmott et al, Baxter and Rennie). The probability that S goes up under the Qmartingale measure is $\frac{u}{(u+1)}$. At t=1, if the stock value has risen, how does one decide whether or not to exercise the option? Given that r=0, one simply wants to see if u-k is greater than or less than the value of the stock at t=2, under the Qmartingale.

The Black Scholes equation for the valuation of the stock in this two period example is $BS = (u^2 - k)\left(\frac{u}{(u+1)}\right) + (1-k)\left(\frac{1}{(u+1)}\right) > u - k$. That is, the value of the stock at t=2 under the martingale measure is greater than the value of the stock at t=1, and we should wait to exercise the option.

There are similarities between an IFQ and a financial option. Like an option, and IFQ gives the holder the right, but not the obligation to harvest a given stock of fish in the future. Also, the IFQ holder must optimally decide when to harvest the fish. However, the holder must factor in two additional considerations. The first is the property rights questions already raised in this paper. The second, is the market timing question. Unlike options, it may not be optimal to wait until the last moment. If every harvester waits until the last moment to exercise the harvest option, there will be a market glut and price will fall, as in the open access case.

6. Property Rights and Market Allocation

The following discussion incorporates uncertainty over property rights into a market allocation model in two time periods.

Consider a fishery with a large number of harvesters. Each owns ifq_i, where $\sum_{i=1}^{n} ifq_i = IFQ$. δ is the discount factor and equals $\frac{1}{(1+r)}$. The inverse demand is given by $P_t = a - bQ_t$.

Now the individual's problem is to max $\begin{matrix} P_1 q_{1i} + \delta\gamma P_2 q_{2i} \\ s.t. q_{1i} + q_{2i} \leq ifq_i \end{matrix}$. That is, the single firm maximizes profits (let costs equal zero) across time periods given a discount factor and a property rights uncertainty. Let the constraint be binding such that $q_{2i} = ifq_i - q_{1i}$. Now the individual's problem becomes:

max $P_1 q_{1i} + \delta\gamma P_2 (ifq_i - q_{1i})$.

The first order conditions are:

$P_1 - \delta\gamma P_2 = 0$.

As long as there is positive harvest in each period, $P_1 = \delta\gamma P_2$.

Notice that if in the initial problem, γ =0, then the individual's problem is to maximize revenue in the current period. Let $\gamma \in [0,1]$. Then, $\frac{P_1}{P_2} = \delta\gamma$, and $\frac{P_1}{P_2} = \frac{1}{(1+u)}$ (from section four, $\gamma = \frac{(1+r)}{(1+u)} = \frac{1}{\delta(1+u)}$).

The harvest will be allocated at the market level via the following:

$$P_1 = a - bq_1$$
$$P_2 = a - bq_2$$
$$\Leftrightarrow P_2 = a - b(IFQ - q_1)$$

where

$$q_1 = \sum_{i=1}^{n} q_{1i}$$
$$q_2 = \sum_{i=1}^{n} q_{2i}$$

Given the no-arbitrage condition, we must allocate harvest in each period so that the present value of prices is equated across time periods.

$$a - bq_1 = \delta\gamma(a - b(IFQ - q_1))$$

Solving for the optimal q_1 and q_2 we get:

$$q_1 = \frac{a(1-\delta\gamma) + \delta\gamma bIFQ}{b(\delta\gamma + 1)}$$

and

$$q_2 = IFQ - \frac{a(1-\delta\gamma) + \delta\gamma bIFQ}{b(\delta\gamma + 1)}$$

Now consider the effect of γ, the property rights specification, on the optimal allocation of q_1 and q_2.

$$\frac{\partial q_1}{\partial \gamma} = \frac{\delta(a - bIFQ)}{b(\delta\gamma + 1)^2} < 0$$

$$\frac{\partial q_2}{\partial \gamma} = -\frac{\delta(a - bIFQ)}{b(\delta\gamma + 1)^2} > 0$$

That is, as property rights are more well specified, more harvest will be allocated to the second period. Whereas, as rights are less well-specified, more harvest will occur in the first period. The extreme case is when γ equals zero. The market models indicate that the optimal harvest in q_1 is $\frac{a}{b}$. However, as determined in section four, there is no value to waiting when γ equals zero. The entire harvest occurs in the first period and q_1 equals IFQ. This is an example of the market failure present in an open access situation. This example also illustrates how improving property rights specification facilitates the market mechanism for resource allocation.

7. Conclusions, Discussion

The North Pacific halibut fishery transition from an open access to an IFQ managed fishery is an example of how changing property rights effect both resource value and harvest.

The IFQ is a marketable right so determining an appropriate value is important. This paper considered traditional valuation tools such as NPV and showed that this framework is inadequate given stochastic prices and uncertainty over property rights. The discussion of the Arrow-Fisher result illustrates that when uncertainty over future conditions exist, there is a value to waiting to harvest. The Black-Scholes option pricing model incorporates the stochastic effects of the market into the value of an IFQ. Given the similarities between options and IFQs, this model may be an appropriate beginning for valuing IFQs. However two differences distinguish the IFQ fishery from the options market: the market effects of exercising the right, and the uncertainty of the property right relating to the asset (the fish harvest).

From a policy standpoint, the insights gained from this study aid in identifying the relationship between markets and property rights systems. For example, to manage negative externalities, it may not be necessary to completely privatize or specify property rights. The degree of specification depends rather, on the relationship between prices, interest rates and property rights structures such as tradability and enforcement.

Based on these conclusions, future study in two areas will be helpful: 1) identify and model the indicators of the property rights framework affecting a resource 2) incorporate property rights elements and market allocation issues into IFQ valuation.

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