The impact of price and yield risk on the bioeconomics of reservoir aquaculture in north Vietnam

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ABSTRACT

A bioeconomic model of reservoir aquaculture in northern Vietnam is used to investigate the impacts of price and yield risk on the level, variability and skewness of expected net revenue and utility. Prices and yields are assumed to follow lognormal and beta distributions, respectively. Net revenue follows a generalized gamma distribution and is found to be very risky compared with similar enterprises elsewhere, mainly due to the relatively high yield risk. This represents the nascent nature of the industry in Vietnam and the opportunity for efficiency improvements. Increasing production capacity (through increasing reservoir size, stocking density, production cycle length and harvest rate) are found to increase profits and decrease the variability of profits. Species diversification was found to reduce the riskiness of the enterprise.

Keywords: bioeconomic modelling, price risk, yield risk, aquaculture, Vietnam,

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1. Introduction

Over the last decade, the Vietnamese government has pursued a program of reservoir construction by damming waterways for the purpose of developing the country's hydroelectric power and irrigation capacity. The reservoirs are a source of livelihood for a large number of relatively poor people, particularly those who lost their land to these reservoirs. The smaller reservoirs are referred to as farmer-managed reservoirs as they are leased to farmers, or groups of farmers, by the provincial authorities for fish production. Management of these reservoirs involves regularly stocking fingerlings of suitable species and harvesting them at marketable size. These fisheries are often augmented by self-recruiting populations of mostly indigenous species (Phan and de Silva 2000).

Farmer-managed reservoir aquaculture in Vietnam is still in its infancy. Reservoir fishery research and development is a growing priority for the government, although to date policy regarding these systems has developed in a relatively *ad hoc* way. Fingerling production has still not reached market capacity and is a significant constraint to the growout of reservoir species. Species combinations and stocking densities are currently not being optimised, rather they are based on fingerling availability. Yields are low, especially when compared with yields of similar species that have been cultured in Sri Lanka and other Asian countries (e.g. Welcommme & Bartley (1998), de Silva (2001) and Wijenayake et al. (2004)).

There is currently a paucity of research being conducted on farmer-managed reservoirs in Vietnamese, especially in terms of improving yields, feeding strategies, and market performance. The Australian government, through the Australian Centre for International Agricultural Research (ACIAR), is collaborating with the Vietnamese Government and universities to conduct some of this research.[1] The analysis presented in this paper is part of one of these ACIAR projects investigating the economics of developing reservoir aquaculture in Vietnam. One component of this project is the development of a bioeconomic model to identify the significant input factors contributing to economic performance given current costs and prices. The model, called BRAVO (Bioeconomic model of Reservoir Aquaculture for Vietnamese Operations), is calibrated for five carp species in northern Vietnamese operations[2], and is described in detail in Petersen et al (2005). Initial results indicate that net revenue from these operations is approximately 9 million Vietnamese Dong (VND) (approximately US$560 at the time of writing) and that costs were dominated by restocking (75 percent) and contract labour (18 percent).

This analysis extends the work of Petersen et al. (2005) to consider the role of price and yield risk on the reservoir bioeconomics and farmer production decisions.[3] Both these variables are risky in this environment. For example, data obtained from the Vietnamese Research Institute for Aquaculture Number 1 (RIA1) indicate that the

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[1] Projects include "Culture-based and capture fisheries development and management in reservoirs in Vietnam (FIS/2001/013) and "The economics of developing reservoir aquaculture in Vietnam" (ADP/2000/018).

[2] A southern application will be conducted when data becomes available.

[3] Note that in this paper, we use the Hardaker et al. (1997) definition of "risk" as "uncertain consequences, particularly exposure to unfavourable consequences" in distinction from the term "uncertainty" which Hardaker et al. define as "imperfect knowledge".

coefficient of variation for carp prices is approximately 10-20 percent, and for carp yields is approximately 40-90 percent. The riskiness of prices is similar to other fish species reported in the literature. For example, Valderrama and Engle (2001) report coefficients of variation for shrimp prices to be approximately 8-15 percent. The riskiness of yields is high compared with other fish production systems reported in the literature. For example, Kazmierczak and Soto (2001) report that the coefficient of variation for channel catfish yields is approximately 5-6 percent. The coefficient of variation of channel catfish net revenue is reported to be somewhat higher at approximately 45 percent. Valderrama and Engle report coefficients of variation for shrimp yields of approximately 20-40 percent and Tveteras (1999) reports that the coefficient of variation of Norwegian salmon yields is approximately 66 percent. Yield risk is high in reservoir aquaculture in Vietnam as it is a nascent industry. The opportunities to improve technology and system efficiency are vast.

An analysis of price and yield risk on reservoir bioeconomics and farmer production decisions is presented here with the following structure. A description of the modeling of price and yield risk in BRAVO is presented in Section 2, starting with a brief overview of BRAVO (Section 2.1) and continuing with specific information on the modeling of risk in BRAVO (Section 2.2). It is noted that prices are assumed to be lognormally distributed and yields are assumed to follow a beta distribution. Results and discussion are presented in Section 3. Monte Carlo analysis is employed to repetitively simulate the impact of price and yield risk on net revenue utility under a range of production scenarios. These scenarios include different reservoir sizes, stocking densities, production cycle lengths, harvest rates and species combinations. A summary of the paper findings and policy implications are presented in the conclusions (Section 4).

2. Modelling price and yield risk in BRAVO

2.1 Brief description of BRAVO

BRAVO is a simulation model of the biology and economics of farmer-managed reservoir aquaculture in northern Vietnam. The biological component is based on a conventional von Bertalanffy growth function (von Bertalanffy 1938), and the economic component is a net revenue function. It is applied to five species commonly cultured in Vietnamese reservoirs; grass carp (*Ctenopharyngodon idella* Cuv. Et Van.), silver carp (*Hypophthalmichthys molitrix* Cuv. Et Val.), bighead carp (*Aristichthus nobilis* Richardson), common carp (*Cyprinus carpio* L.) and mrigal (*Cirrihinus mrigala* Hamilton). These species do not share overlapping ecological niches, hence there is assumed to no inter-specific competition for food in BRAVO. The data in BRAVO is calibrated for reservoirs of size 1 to 80 hectares, with the standard model using the average reservoir size of 20 hectares.

Stocking and harvest times are dependent on the hydrology of the reservoirs. Water levels are at a minimum around late February to late April when water is drained for irrigation purposes. Harvesting is conducted during this time. The reservoirs are restocked soon afterwards when waters levels rise. In the standard version of BRAVO, an 11.5 month production cycle is assumed. However, this is able to be adjusted by the user. There is very little management of these fisheries other than the guarding of reservoirs against poachers and the occasional feeding of tender cassava leaves and, in small reservoirs (less than 5 hectares), rice bran and fermented cassava tubers. Feeding is not included in BRAVO, rather fish are assumed to gain all their nutritional requirements from natural feed sources in the water body. With the development of these fisheries, it is likely that feeding will become more prevalent and should be introduced into BRAVO in future research. Contract labour for guarding and harvesting is fully costed. For more information on BRAVO, readers are referred to Petersen et al. (2005).

2.2 Modeling risk in BRAVO

The mean and standard deviation of fish prices is taken from an unpublished dataset collated by staff at RIA1. This dataset includes the price and weight of fish sold in 2003 at 12 reservoirs in each of two northern provinces, Thai Nguyen and Yen Bai. The mean harvest prices for different fish species (before risk is introduced) are presented in Table 1.

Table 1: Assumptions on the mean harvest price for different fish species by weight (VND/kg)

Fish size at harvest (kg)	Common carp	Silver carp	Grass carp	Bighead carp	Mrigal
< 0.4	11,500	4,500	11,000	5,500	9,000 (26)
0.4 - 0.5	11,500 (27)	4,500 (14)	11,000	5,500	12,500 (23)
0.5 - 1.0	14,000 (33)	5,500 (45)	11,000 (6)	5,500	12,500
1.0 - 1.2	14,000	5,500	13,500 (5)	5,500	12,500
1.2 - 1.5	14,000	5,500	14,500 (17)	5,500 (31)	12,500
> 1.5	14,000	5,500	15,000 (12)	6,500 (22)	12,500

Note: Numbers in brackets indicate the size of the data sample from which these average prices are taken. For example, there were 27 available data points for prices of Common carp of a weight less than 0.5kg and 33 available data points for prices of the same species weighing greater than 0.5kg.

Prices are assumed to be lognormally distributed as they cannot be negative and can, in theory, reach infinity. Tables 2 and 3 show the new mean and standard deviation of fish price after taking the natural log of each data point.

Table 2: Assumptions on the mean harvest price for different fish species by weight from *logged* data

Fish size at harvest (kg)	Common carp	Silver carp	Grass carp	Bighead carp	Mrigal
< 0.4	9.322	8.384	9.308	8.585	9.072
0.4 - 0.5	9.322	8.384	9.308	8.585	9.072
0.5 - 1.0	9.529	8.592	9.308	8.585	9.418
1.0 - 1.2	9.529	8.592	9.506	8.585	9.418
1.2 - 1.5	9.529	8.592	9.588	8.585	9.418
> 1.5	9.529	8.592	9.612	8.791	9.418

Table 3: Assumptions on the standard deviation of harvest price for different fish species by weight from *logged* data

Fish size at harvest (kg)	Common carp	Silver carp	Grass carp	Bighead carp	Mrigal
< 0.4	0.132	0.090	0.108	0.093	0.184
0.4 - 0.5	0.132	0.090	0.108	0.093	0.184
0.5 - 1.0	0.086	0.146	0.108	0.093	0.100
1.0 - 1.2	0.086	0.146	0.106	0.093	0.100
1.2 - 1.5	0.086	0.146	0.074	0.093	0.100
> 1.5	0.086	0.146	0.090	0.108	0.100

A random variable X has a lognormal distribution if its logarithm, $Y = \log(X)$, has a normal distribution. Hence, price risk is included in BRAVO (an Excel-based model) by generating random numbers for each species from a normal distribution given means and standard deviations shown in Tables 2 and 3. This is done by utilizing the random number generator in Poptools, a statistical package that emulates a subset of the analytical and statistical methods that are available in advanced mathematical and statistical programs (eg, Mathematica, Matlab, S-Plus, Genstat).[4] The exponential of these random price values is then taken to convert them to VND/kg values for the net revenue function.

Data used for determining the mean and standard deviation of fish yields also come from an unpublished dataset collated by staff at RIA1. This dataset includes the stocking and harvest densities (in kg/ha) of fish species in the same two northern provinces (Thai Nguyen and Yen Bai) over two production cycles (2002/03 and 2003/04). Eight sets of data were collected for each species in Thai Nguyen and 12 for Yen Bai for each production cycle. Hence a total of 40 data points (8x2 + 12x2) were collated for each species. Stocking efficiencies were calculated from this data, where stocking efficiency is defined as the ratio of fish yield (kg/ha) to fish stocked (kg/ha) (Li 1987). The mean, standard deviation and coefficient of variation of these stocking efficiencies are presented in Table 4. The coefficient of variation of stocking efficiency is high compared with other studies (see introduction), ranging from 44 percent for Mrigal to 85 percent for Common carp.

Table 4: Assumptions on stocking efficiencies for different fish species

Species	Mean stocking efficiency	Standard deviation of stocking efficiency	CV of stocking efficiency (%)	Mean for beta distribution	Standard deviation for beta distribution
Common carp	3.8	3.2	85	0.272	0.230
Silver carp	3.4	1.9	55	0.246	0.136
Grass carp	3.7	2.3	62	0.268	0.168
Bighead carp	4.6	2.5	54	0.333	0.180
Mrigal	3.2	1.4	44	0.230	0.101

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[4] Poptools can be downloaded from http://www.cse.csiro.au/poptools/

In the absence of direct yield variability data, the variation in stocking efficiency is assumed to reflect the variation in harvest yields represented in BRAVO. Yields are expected to follow a Beta distribution. Yield risk is included in BRAVO by generating random numbers for each species from a beta distribution, once again utilizing Poptools. For convenience, Poptools parameterizes most random variables by their mean and standard deviations using what it calls a pseudo random number generator.[5] The mean and standard distribution for the beta distribution must range between 0 and 1 and are calculated by dividing the mean (in this case, of stocking efficiency) by the maximum value in the data (see Table 4). Mean stocking efficiencies for the beta distribution range between 0.230 in the case of Mrigal and 0.333 in the case of Bighead carp, indicating that the distributions are skewed to the right.

These random yield values are then converted to kg/ha values by multiplying them by the total possible harvest weight (see column E, Table 5). This total possible harvest weight is estimated by multiplying the total harvest weight in the absence of risk (column C, Table 5) by the inverse of the mean for the beta distribution (column D, Table 4).

Table 5: Assumptions on stocking and harvest rates assuming a 20ha reservoir

		A	B	C = A x B x 20ha	D[a]	E = C x D
Species	% of each species stocked	#/ha harvested	Mean fish weight at harvest (kg)	Total harvest weight (kg)	Multiplying factor	Max possible harvest weight (kg)
Common carp	6	9	0.445	82	3.7	302
Silver carp	38	78	0.941	1,465	4.1	5,956
Grass carp	21	22	1.146	493	3.7	1,841
Bighead carp	6	7	1.446	213	3.0	641
Mrigal	29	89	0.395	704	4.3	3,063
Total	**100**	**205**		**2,958**		**11,803**

[a] D is the inverse of the mean for the beta distribution (column 5, Table 4). As 1 represents the maximum harvest using the beta distribution, 1 divided by the mean multiplied by the total harvest weight represents maximum possible harvest weight.

The net revenue function in BRAVO is given by:

$$NR = TR - TC \qquad (1)$$

where: NR = net revenue (VND);
TR = total revenue (VND); and
TC = total costs (VND).

Total revenue is a function of harvest weight and prices:

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[5] The algorithms are from AMRandom library written by Alan Miller and translated from Fortran by Glen Crouch - see www.esbconsult.com.au

$$TR = \sum_{i=1}^{5} W_{H_i} * P_{H_i} \qquad (2)$$

where: W_{Hi} = the weight of each species, *i* (kilograms, kg); and

P_{H_i} = the price of each species, *i* (VND/kg).

Note that the standard version of BRAVO allows for three different harvest times. However, staggered harvesting has been omitted from this analysis. Total costs are a function of restocking costs and a number of miscellaneous fixed costs such as interest payments, contingency, the cost of replacing a net and boat every five years, and contract labour. Restocking costs are a function of the price of fingerings, the weight of fingerlings, and the number of fingerlings stocked. Fingerling price and yield risk are not included in this analysis.

This analysis determines the impact of price and yield risk on a farmer's expected level and variance of net revenue. It also investigates which of these effects dominates to determine the overall impact on utility. To do this, it is necessary to specify a functional form for the farmer's utility of net revenue, *U(NR)*. It is assumed that this utility function is given by the constant absolute risk aversion form (CARA):

$$U(NR) = 1 - \exp(-NR / R) \qquad (3)$$

where R = the coefficient of absolute risk aversion. R is positive for risk aversion and increases for increasing NR if there is diminishing risk aversion. A property of CARA is that the preferred option in a risky choice situation is unaffected by the addition or subtraction of a constant amount to all payoffs (Hardaker et al. 1997). While this is not usually regarded as a desirable property, this functional form allows for negative payoffs (in our case, negative net revenues), unlike functional forms for constant relative risk aversion.

Because data on prices and yields were obtained separately, there is no information on the covariance of prices and yields. This study assumes a covariance of zero, and hence, over-estimates the impact of price and yield risk on net revenue. However, initial analysis not reported here indicates that the impact of covariance on expected net revenue is minimal.

Monte Carlo analysis (repeated sampling from probability distributions of model inputs to characterize the distributions of model inputs) is used to simulate the impact of price and yield risk on expected net revenue under a number of different production scenarios. 1000 replicates are used for each result.

3. Results and Discussion

3.1 Standard model results

Standard model results in the presence and absence of risk are shown in Tables 6 to 8. Standard model assumptions include a reservoir size of 20ha, a stocking density of 24.5kg/ha (this is dependent on reservoir size, see Petersen et al. (2005)), a production cycle of 11.5 months, a harvesting percentage of 12.5 percent (also dependent on reservoir size, see Petersen et al. (2005)) and species combinations as shown in Table 5. Each of these assumptions will be relaxed in Section 3.2.

Standard model results, where a lognormal distribution is used for prices and a beta distribution is used for yields, are presented in Table 6. Expected net revenue is slightly higher than net revenue (the latter in the absence of risk). The coefficient of variation of expected net revenue is 80 percent. This is relatively high compared with other studies. For example, Kazmeirczak and Soto (2001) report a coefficient of variation for net revenue of 45 percent for channel catfish. However, Kazmeirczak and Soto used coefficients of variation of yield between 5 and 6 percent, a lot lower than the riskiness of yield used here. The net revenue distribution is slightly skewed to the left.

Table 6: Standard model results model without and with risk

	Without risk, NR	With risk, E(NR)	With risk, EU
Lognormal distribution for prices and beta distribution for yields			
Expected value	8.79 (million VND)	9.04 (million VND)	8.97 (thousand utils)
CV (%)		80.3	80.1
Skewness		0.505	0.484

From Table 6 it can be seen that the coefficient of variation and skewness of utility is similar to that of expected net revenue, although slightly lower in both cases. Though results are not shown here, increasing risk aversion has the effect of increasing expected utility and decreasing the riskiness and skew of utility. Hence, farmers are willing to accept a lower level of variation in utility where risk aversion is relatively high.

Two distribution functions are estimated from output data and displayed in Figure 1, a lognormal distribution and a generalised gamma distribution. It appears that the generalised gamma distribution fits the data the best. Whether farmers expect their net revenue function to follow a generalised gamma distribution, normal distribution, or some other distribution, is not known. However, it can be said that if they assume it to follow a normal distribution, then he or she will underestimate the probability of obtaining high net returns. Thus, under an assumption of normality, producers may make decisions that place their operations in a poorer financial position than they otherwise would if they understood the true distribution of their expected net returns.

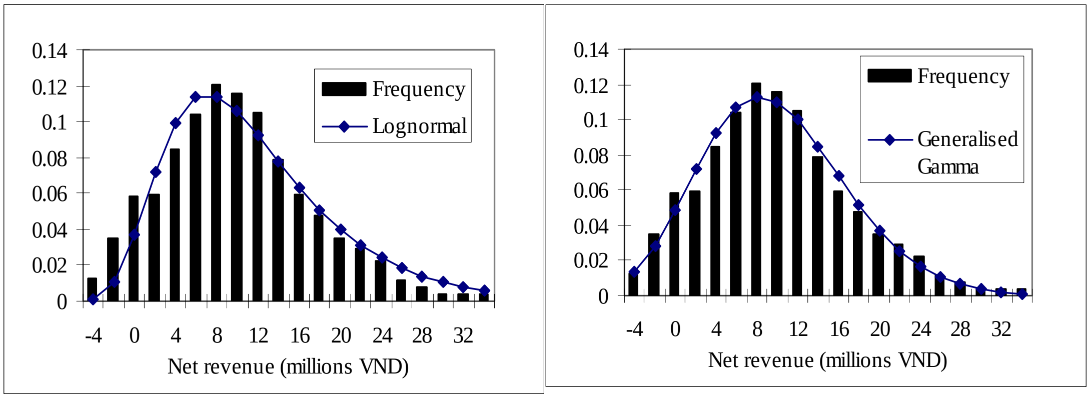

Figure 1: Histograms of net revenue in the presence of price and yield risk showing estimated lognormal and generalised gamma distributions

Note: Each column represents the upper bound of a set of results where the minimum and maximum net revenue values have a difference of 2million VND. For example, column labelled -4 represents the set of results where net revenue is between -6 million to -4 million VND.

Table 7 contains results where symmetric distributions are used - a normal distribution for prices and a symmetric beta distribution for yields. When compared to the scenario of non-symmetric distributions (Table 6), NR, E(NR) and EU are very similar. However, the coefficient of variation and skewness of E(NR) and EU are lower. Hence, the non-symmetric distributions have the effect of increasing the riskiness and skewness of expected net revenue.

Table 7: Model results without and with risk assuming symmetrically distributed prices and yields

	Without risk, NR	With risk, E(NR)	With risk, EU
Symmetrically distributed prices and yields			
Expected value	8.79 (million VND)	8.97 (million VND)	8.90 (thousand utils)
CV (%)		74.8	74.7
Skewness		0.0551	0.0382

Model results with a halving of the yield risk assumptions are presented in Table 8. The expected values and skewness are largely unaffected, but the coefficient of variation of E(NR) and EU is almost halved. Hence, yield risk has a significant impact on the riskiness of net revenue and utility.

Table 8: Model results where yield risk is halved

	Without risk, NR	With risk, E(NR)	With risk, EU
Lognormal distribution for prices and beta distribution for yields			
Expected value	8.79 (million VND)	9.02 (million VND)	8.97 (thousand utils)
CV (%)		42.3	42.1
Skewness		0.483	0.471

3.2 Sensitivity analysis on key model assumptions

Sensitivity analysis is conducted on five key model assumptions; reservoir size, stocking density, production cycle length, rate of harvest and species combination. Model results presented here include net revenue in the absence of risk, and expected net revenue, the coefficient of variation and skewness in the presence of risk. Results using utility and symmetric price and yield distributions were computed, but yielded trends similar to the standard model. Hence, they are not included in the discussion below.

Model results for different reservoir sizes are shown in Table 9. As one would expect with increasing input capacity, increasing reservoir size has the impact of increasing NR and E(NR). CV_{NR} decreases with increasing reservoir size even without explicitly including covariance between prices and yields. There seems to be no obvious pattern in skew. It appears that increasing reservoir size causes the riskiness of prices and yields to combine to decrease the riskiness of net revenue (i.e. there are "risk" economies of scale). This may be the result of inefficient reservoir size and should be the topic of further study.

Table 9: Model results for different reservoir sizes

Reservoir size (ha)		5	10	*20 (standard)*	40	60	80
No risk	NR (million)	4.82	6.55	*8.79*	11.9	14.3	16.5
With risk	E(NR) (million)	4.82	6.80	*9.04*	12.2	14.1	16.3
	CV_{NR} (%)	98.4	82.1	*80.3*	70.7	70.5	65.5
	Skew	0.594	0.375	*0.505*	0.436	0.348	0.462

Stocking density, production cycle length and rate of harvest assumptions are relaxed in Tables 10, 11 and 12, respectively. A pattern in the results appears, similar to that found with increasing reservoir size. Increasing stocking density, production cycle length and harvesting rate have the impact of increasing NR and E(NR), and decreasing CV_{NR}. Hence, there are profit level and risk advantages in increasing the size of the enterprise through increasing stocking density, production length and harvest rate. Optimal levels of each of these parameters should be the topic of further study.

Table 10: Model results for different stocking densities

Stocking densities (kg/ha)		0.5 x standard (12.3)	0.75 x standard (18.4)	*1.0 x standard (24.5)*	1.5 x standard (36.8)	2.0 x standard (49.0)
Without risk	NR (million)	2.61	5.70	*8.79*	15.00	21.2
With risk	E(NR) (million)	2.54	5.51	*9.04*	14.2	21.6

	CV_{NR} (%)	132	96.8	*80.3*	72.7	67.0
	Skewness	0.325	0.574	*0.505*	0.532	0.385

Table 11: Model results for different production cycle lengths

Length of production cycle (months)		9.5 months	10.5 months	*11.5 months (standard)*	12.5 months	13.5 months
Without risk	NR (million)	1.50	4.57	*8.79*	16.7	21.6
With risk	E(NR) (million)	1.55	4.68	*9.04*	12.4	19.9
	CV_{NR} (%)	313	118	*80.3*	70.2	53.0
	Skewness	0.502	0.478	*0.505*	0.581	0.505

Table 12: Model results for different rates of harvest

Harvesting percentage		0.5 x standard (6.3)	0.75 x standard (9.4)	*1.0 x standard (12.5)*	1.5 x standard (18.8)	2.0 x standard (25.1)
No risk	NR (million)	-2.68	3.06	*8.79*	20.3	31.7
With risk	E(NR) (million)	-2.78	2.89	*9.04*	20.6	32.8
	CV_{NR} (%)	-125	180	*80.3*	50.8	43.2
	Skewness	0.493	0.393	*0.505*	0.436	0.383

Now consider the results with different species combinations. Currently, the predominant species stocked are Silver carp, Mrigal and Grass carp. These species have high net revenue per percent stocked (see Table 13). Bighead carp also has a high net revenue per percent stocked but is stocked at low quantities. This may be due to constraints on the availability of this species. Mrigal has the highest price risk, and Common carp has the highest yield risk. The combined effect of price and yield risk per species is that Common carp is extremely risky with net revenue between 8 and 10 times that of the other species. There appears to be an inverse relationship between net revenue per percentage stocked (row A, Table 13) and the riskiness of net revenue (row B, Table 13), with Grass carp being the most lucrative and the least risky, and Common carp being the least lucrative and the most risky.

Table 13: Stocking rates, net revenue per percent stocked and the riskiness of price, yields and net revenue for different fish species

	Species	Common carp	Silver carp	Grass carp	Bighead carp	Mrigal
	% of each species stocked	6.00	38.0	21.0	6.00	29.0
A	NR/% stocked - without risk (VND)	12,500	86,800	153,000	75,200	68,800
	CV_{price} (%)	12.8	13.9	10.5	9.61	17.9
	CV_{yield} (%)	84.6	55.3	62.7	54.0	43.9

B	CV_{NR} (%)	1290	142	127	145	169

Changing the species combinations has a marked effect on NR, E(NR) and CV_{NR} (Table 14). Stocking Grass carp only is a high return, low risk strategy. Stocking Common carp only is a low return, high risk option. CV_{NR} is minimized by stocking a combination of species. Hence, diversification reduces the riskiness of the enterprise. Unreported results suggest that in the presence of risk, the net revenue impacts dominated the risk impacts so that Grass carp monoculture maximizes expected utility.

Table 14: Model results for different species combinations

Proportion of species stocked		*Standard*	100% Common carp	100% Silver carp	100% Grass carp	100% Bighead carp	100% Mrigal
No risk	NR (million)	*8.79*	0.867	8.86	14.7	7.58	6.31
With risk	E(NR) (million)	*9.04*	1.23	8.98	14.9	7.52	6.18
	CV_{NR} (%)	*80.3*	1090	129	138	144	170
	Skewness	*0.505*	0.827	0.848	0.701	0.624	0.871

4. Conclusions

This paper presents an analysis of the impact of price and yield risk on the bioeconomics of north Vietnamese reservoir aquaculture. It employs a simulation model of the biology and economics of farmer-managed reservoir aquaculture in northern Vietnam. Monte Carlo analysis is used to repetitively simulate the effect of price and yield risk on the level and riskiness of expected net revenue and utility under a number of different production scenarios.

Results are summarised as follows. Yield risk is high compared with price risk (40 to 90 percent compared with 10 to 20 percent, respectively, depending on the species). Moreover, yield risk is high compared with that presented in other aquaculture applications. This is a reflection of the emerging nature of reservoir aquaculture in Vietnam, and represents significant opportunity for technology and efficiency improvement. Net revenue is also high relative to other studies, mostly a result of the relatively high yield risk.

Prices are log-normally distributed and yields follow a beta distribution. Net revenue was found to follow a generalized gamma distribution. If farmers perceive their expected net revenue to follow a normal, rather than generalized beta distribution, then it is likely that they will make production decisions that place their operations in a poorer financial position than they otherwise would if they understood the true distribution of their expected net returns.

The model was run under a number of different scenarios that affect production capacity; reservoir size, stocking density, production cycle length and rate of harvest. Results suggest that increasing capacity in these ways has the effect of increasing expected net revenue and lowering the riskiness of net revenue. These results suggest that there are large efficiency gains to be exploited through increasing production. Investigating optimal production capacity is an important topic for further research.

The analysis also considered the impact of species combination on reservoir bioeconomics. Each species has different price and yield variability. Mrigal was found to be most risky in terms of price and Common carp was found to be most risky in terms of yield and species net revenue. When risk was excluded from the analysis, farm monocultures of Grass carp were found to maximize net revenue. However, when risk was included, a combination of species was found to minimize risk, although the net revenue impacts dominated the risk impacts so that Grass carp monoculture maximized expected utility.

A number of policy implications can be drawn from these finding. Large reservoirs appear to have an advantage over smaller reservoirs, both in terms of level and riskiness of net revenue. Historically, reservoirs have been constructed in northern Vietnam primarily for irrigation purposes. Increasing the size of further reservoir construction is likely to improve the level and riskiness of fisher livelihoods. Reservoirs in southern Vietnam are constructed for hydropower production and are generally larger. Further analysis is needed to determine whether these reservoirs are more profitable relative to the northern Vietnamese reservoirs.

Farmer-managed reservoirs in northern Vietnam are not performing efficiently, and there are significant opportunities to improve technology and management to increase income and decrease the riskiness of income, the latter of which is being driven by yield risk. Further study into determining the economically efficient farm size, stocking density, production cycle length, harvest rate and combination of species is likely to have significant impacts on the welfare of reservoir fishers. Developing BRAVO to be an optimisation, rather than simulation, model would aid facilitation of this research. Other BRAVO developments, such as including feeding and calibrating it for the south of Vietnam, would also increase the breadth of analysis that could be performed using the model, and are laudable topics for further research.

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