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ECONOMIC EVALUATION OF MULTIPLE RESEARCH INNOVATIONS ON AN EEL FARM

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Abstract

An approach for evaluating multiple innovations of an aquaculture farm is proposed, based on a model of induced innovations, supplemented with a bio-economic table for the calculation of production function. Data gathered from a model eel farm were used as an example. The proposed approach enables evaluating each innovation to determine which is the most profitable.

Introduction

Innovations in industries such as aquaculture are often generated by multiple research lines related to a variety of regimes (e.g., diet, density, hormone application) and growth stages. Evaluation of complex innovations requires tools to assess economic advantages and aid in dividing the expected benefits between growers and technology transfer institutions and between the different research lines. The induced innovations model developed for multiple research lines (SZ-model, Sunding and Zilberman, 2001) provides a clear link between farm production and input costs and the price of a single research line (innovation price). In other words, it provides for dividing the expected benefits between different research lines but does not include a mechanism for dividing the expected benefits between growers and research teams.

In our empirical study, the SZ-model was

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modified to clearly divide the expected benefits between growers and research teams based on evaluation of multiple research lines on an eel farm. The model relates to a number of biological parameters at three stages of eel growth and incorporates a bio-economic representation of the production function based on studies of eel growth models (Dekker, 2000; De Leo and Gatto, 2001) and data from laboratory experiments (Degani and Gallagher, 1995).

Materials and Methods

Modification of the SZ-model for an eel farm. A modified SZ-model was developed for an eel farm that conducts three growth stages: glass eels during the first three months, elvers during the next nine months, and yellow eels to market size at 1.5-5 years. The model was formulated as follows:

(1)

$$\max_{X_i,\, m_{jk}} \left(\Pi = pY - \sum_{i=1}^{1} w_i X_i - \sum_{k=1}^{3}\sum_{j=1}^{J_k} (v^f_{jk} + v^t_{jk})\, m_{jk}\right)$$

where Π is the profitability of the farm that produces Y units of biomass of eels at price p, X_i is the input i while the input unit price is w_i, J_k is the number of research lines at growth stage k, m_{jk} is the number of units (intensity) of the j^{th} research line at stage k, v^f_{jk} is the unit cost of line jk that represents the farm's expenses relative to the transformed innovation and v^t_{jk} is the unit price of line jk (innovation price) that serves as a source of profit for the innovation team.

The difference of model (1) from the SZ-model is in the representation of the innovation price of line jk by the sum of two terms, v^f_{jk} and v^t_{jk}. The prices v^t_{jk} multiplied by intensities and summarized by all considered research lines give the research team's share of the expected benefits. The costs v^f_{jk} allow evaluating the additional farm expenses related to the innovation. After evaluating the additional farm profit and the research team's share of the expected benefits, the balance expressing the farm's expected benefits can be calculated.

As a result of applying the innovation, the production function (biomass Y) increases due to the multiplicative effect of the research lines and changes in the farm's inputs:

(2)

$$Y = g(m) \bullet f(h_1(m) \bullet X_1(m), \ldots, h_I(m) \bullet X_I(m))$$

where $m = \{m_{11},\ldots,m_{J_1 1}, m_{12},\ldots,m_{J_2 2}, m_{13},\ldots, m_{J_3 3}\}$ is the vector of intensities of the research lines in the innovative technology for the three stages of growth, $g(m)$ is the multiplicative effect of the research lines, $h_i(m)$ is the effect of the innovative technology on the i input, and $h_i(m) \cdot X_i(m)$ is the effective i input.

Based on experiments conducted for a number of possible intensities on each of the research lines, a bio-economic table can be calculated. This table includes the following data related to pre-defined values of intensities of the research lines: (1) effective inputs, (2) cost of the research lines for the farm and (3) expected biological characteristics such as the coefficient of fish survival s and fish growth rate $\partial\omega/\partial t$ (g/day). After dividing the three growth periods into small sub-periods Δt, the following model was used to describe changes in eel biomass over time:

(3)

$$Y_t = s_t \bullet N_{t-1} \bullet \left(\omega_{t-1} + \frac{\partial\omega}{\partial t} \bullet \Delta t\right)$$

where s_t is the coefficient of survival of eels at period t, N_{t-1} is the number of fish in period $t-1$, ω_{t-1} is the weight (g) of one eel at period $t-1$ and $\partial\omega/\partial t$ is the growth rate (g/day) of eels at period t. After combining the bio-economic table and function (3), a production function (2) may be calculated.

Using the first-order conditions for the SZ-model, the innovation prices v^t_{jk} may be calculated from the following equation:

(4)

$$m_{jk} v^t_{jk} = pY \bullet e^g_{m_{jk}} + \sum_{i=1}^{1} w_i X_i \varepsilon^{h_i}_{m_{jk}} - m_{jk} v^f_{jk}$$

where

(5)

$$e^g_{m_{jk}} = \frac{\partial g}{\partial m_{jk}} \bullet \frac{m_{jk}}{g(m)}$$

is the elasticity of the multiplicative effect of innovation with respect to intensity of the jk research line, and

(6)

$$\varepsilon^{h_i}_{m_{jk}} = \frac{\partial h_i}{\partial m_{jk}} \bullet \frac{m_{jk}}{h_i}$$

is the elasticity of the effect of the innovative technology on the *i* input with respect to intensity of the *jk* research line.

If the vector of intensities

$$\left\{ m^0_{11},\dots, m^0_{J_1 1}, m^0_{12},\dots, m^0_{J_2 2}, m^0_{13},\dots, m^0_{J_3 3} \right\}$$

and the vector of inputs $X^0_1, \dots, X^0_I$ solve problem (1), equations (4) and (1) allow the optimal value of the profit Π to be calculated. Thus, assuming that the examined vectors of intensities and inputs are optimal, the bio-economic table used to enumerate all potential innovations will provide a numerical solution to problem (1).

Data. The data were gathered from a model eel farm in Kibbutz Dan in northern Israel (Anon., 2000). The following inputs were used in the empirical model: discounted capital investment, labor, water, feed, energy, veterinary expenses and sales costs. The model farm data include actual and innovative costs of inputs, initial quantity of glass eels (2.273 million), capacity of water reservoirs and their costs for three growth stages, and purchase price of the glass eels.

Regimes for potential innovations were identified for each growth stage. Several research lines were studied for every regime, each line at 3-4 levels of intensity: water temperature, percentage of fat and protein in diet, fish density and concentration of hormones. The number of possible combinations of these research lines at different levels of intensity, and for all three growth stages needed for evaluation and comparison, is 216,000. A summary of biological parameters for the research lines studied (Degani and Gallagher, 1995) is presented in Table 1.

Results

An excerpt from a numerical solution for model (1) is presented in Table 2. The research benefits were compared for two research lines at the first growth stage. This example shows that the first research line provides US$5,866

Table 1. Research lines and their biological parameters.

Growth stage	*Innovation*	*No. research lines*	*Coefficient of survival*				*Growth rate, g/day*			
			Farm level	*min*	*avg*	*max*	*Farm level*	*min*	*avg*	*max*
1	Diet (type)	5	0.60	0.0067	0.70	0.77	0.004	0.001	0.005	0.013
	Density (kg/m2)	2	0.60	0.37	0.70	0.96	0.004	0.001	0.09	0.015
2	Hormones (mg/kg diet)	5	0.70	0.70	0.70	0.70	0.040	0.004	0.021	0.051
	Diet (type)	3	0.70	0.70	0.70	0.70	0.040	0.008	0.051	0.113
3	Hormones (mg/kg diet)	2	0.94	0.94	0.94	0.94	0.240	0.264	0.326	0.383
	Density (kg/m3)	2	0.94	0.94	0.94	0.94	0.240	0.240	0.268	0.321

profit for the research team at a stocking density of 2.5 kg/m^2 and an additional $122,045 profit for the farm. The second research line provides $7,304 additional profit for the research team at water temperature 27°C and $139,205 for the farm. Characteristics of the most profitable innovation based on all research lines presented in Table 1 are summarized in Table 3.

The value of farm profit Π was calculated for every potential innovation, using the bio-economic table to assess the value of the production function and the cost of inputs, and by evaluating innovation prices from equation (4), assuming optimality of the innovation. A computer program that enumerated the effects of all possible innovations as combinations of the research lines showed the eel farm's most profitable innovations and its characteristics. The results (Table 3) show that the profit for the innovation team at stages 1 and 3 is significantly higher than for stage 2. Mathematically, this can be explained by larger values of elasticity $\varepsilon^{g}_{m_{jk}}$ and $\varepsilon^{h_i}_{m_{jk}}$ that

Table 2. Example of a numerical solution - intermediate calculations related to growth stage 1 allow comparison of two research lines.

Stages of calculation and values evaluated	*Research line 1 Decreasing stocking density, water changed 24 times daily*			*Research line 2 Diet 5% chicken oil at three temperatures*		
	10 kg/m^2	*5 kg/m^2*	*2.5 kg/m^2*	*23°C*	*25°C*	*27°C*
Input parameters						
Coefficient of survival	0.96	0.96	0.96	0.7	0.7	0.7
Growth rate, g/day	0.0011	0.0053	0.0061	0.0018	0.0067	0.0102
Production function (3), kg	938	1,767	1,920	780	1,480	1,989
Elasticity of multiplicative effect of innovation with respect to intensity of the research line						
Effect of research line, see (2)	1.7147	3.2430	3.5517	1.6548	3.3340	4.7411
Derivative of effect, see (5)	0.0000	1.4476	0.1333	0.0000	1.8876	1.3728
Elasticity of effect (5)	0.0000	0.2232	0.0375	0.0000	0.4404	0.2896
Elasticity of effect of the innovative technology on the input with resepect to intensity of the reserch line						
Effect of technology on input, see (2)	1.05	1.06	1.09	2.8742	3.6239	4.3736
Derivative of effect, see (6)	0.001	0.047	0.047	0.0010	3.3736	3.3736
Elasticity of effect on input (6)	0.0002	0.0223	0.0437	0.0002	0.7241	0.7714
Economic indices, US$						
Farm's expenses relative to innovation, see (1)	-3,695	-3,051	-1,763	28,394	39,752	51,110
Profit for research team (4)	3,710	12,344	5,866	-28,382	17,313	7,304
Additional profit for farm, see (1)	-123,409	83,864	122,045	-163,068	11,932	139,205

Table 3. Characteristics of the most profitable innovation and its research lines.

Characteristic	*Thousand US$*	*Part of additional profit (%)*
Farm profit before innovation	2367	
Profit after innovation	6307	
Additional profit, total for farm and innovation team	3940	100
Additional profit for farm	2635	66.9
Research lines: profit for innovation team		
Stage 1		
Diet 10% chicken oil, water 25°C	433	11
Density 10 kg/m^2, water changed 24 times daily	47	1.2
Total stage 1	479	12.2
Stage 2		
Hormone insulin 40 ppm	10	0.3
Diet 20% lipids, water 25°C	45	1.1
Total stage 2	55	1.4
Stage 3		
Hormone human chorionic gonadotropin in groups of isolation	498	12.6
Density 60 kg/m^3, water recirculation system	272	6.9
Total stage 3	770	19.5
Total for the innovation	1305	33.1

are substituted in equation (4) to calculate innovation prices. The results reflect a significant improvement in the biological characteristics crucial for profitability of the model eel farm, namely an increase in the survival coefficient at stage 1 (0.82 compared with the farm level of 0.6) and in growth rate at stage 3 (0.35 g/day compared with the farm level of 0.24 g/day). The highest profit for the innovation team is achieved with the research lines "10% chicken oil diet, water 25ºC" in stage 1 and "hormone human chorionic gonadotropin in groups of isolation" in stage 3. These research lines are both characterized by low costs to the farm and high elasticity $\varepsilon^{g}_{m_{jk}}$ of the multiplicative effect.

Conclusions

The modified SZ-model of induced innovations allows dividing expected benefits between farmers and research teams based on evaluation of multiple research lines.

The model was applied to an eel farm to compare numerous possible innovations, each of which included multiple research lines at different levels of intensity. To incorporate knowledge about fish cultivation into the SZ-model, the calculation of a production function based on experimental data and on a model (3) that describes changes in eel biomass was applied. This enabled calculating innovation prices for each of the potential innovations, assuming it provided a solution for the SZ-model, enabling finding the most profitable innovation. The ability to assess innovation prices by specific research lines and growth stages is a valuable feature of the proposed approach of evaluating the innovation process in aquaculture.

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