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Full Length Research Paper

Technical Change and Productivity Growth in Iranian Rainbow Trout Aquaculture: An Analytical Approach

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Rainbow trout farming is an important contributor to the aquaculture industry in Iran. This study number of the factors including the socio-economic factor was considered for analysing the factors affecting technical change in trout aquaculture. A two-stage estimation procedure for this analysis was applied. The Malmquist index is then employed to measure the productivity and technical change in the first stage, while the pooled logit and tobit models were performed in the second stage so as to ascertain factors affecting the technical change or innovation improvement. The study was conducted to utilize panel data of 207 trout farms in the country over a five-year period from 2003 to 2007. The results of this study revealed that the total factor productivity (TFP) growth of rainbow trout farming in the aquaculture sector is substantially formed from technical efficiency change rather than technical change or innovation improvement. Hence, Iran still has a room to improve the TFP growth in the trout aquaculture, and this can be done by shifting its production frontier through improving innovation and development of new technologies. Based on the marginal effects analysis derived from the pooled logit/tobit regression, the factors that mostly affected technical change positively were suitability of water temperature (13 to 18°C), extension workshop and educational level of the manager. Conversely, the negative factors included the governmental insurance coverage, pond size and being government tenure, such as public companies and cooperatives.

Key words: Rainbow trout, total factor productivity (TFP) growth, technical change, pooled logit, pooled tobit, marginal effect.

INTRODUCTION

There is an old proverb stating, “give a man a fish and you feed him for a day, teach him how to fish and you feed him for a lifetime”. Nonetheless, this particular proverb does not hold true in the present situation. As the human population increases and natural fisheries resources diminish, knowing how to fish is simply not enough for today’s fishers and their families. The alternative way is aquaculture, which has also become a major income-generating component in the integrated rural development programmes (Singh, 2003). Today, aquaculture activities play a vital role in diminishing demand pressures caused by increasing fish aquaculture activities play a vital role in diminishing demand pressures caused by increasing fish consumption and over-exploitation of fishery stocks. According to global statistics (FAOSTAT, 2009), the world’s aquaculture has grown dramatically during the past half-century. This could be seen from a production of below 1 million MT in the early 1950s, which has risen to 51.7 million MT, with a value of US$78.8 billion. If aquatic plants are included, the world’s production of aquaculture in 2006 was 66.7 million MT, with a total value of US$85.9 billion. As previously mentioned, aquaculture has an essential role in satisfying the demand for human

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consumption of fish and fishery products.

It is important to note that aquaculture has continued to grow more rapidly than all other animal food-producing sectors, while the world's production of captured fisheries had stopped growing over the past two decades. In addition, there are evidences indicating that aquaculture increasingly contributes to food security, poverty alleviation and social equity (Adeli, 2006; FAO, 2009).

Iran has a great capability for fishery activities. About 2,700 km of coastal area in the southern and Northern Iran and hundreds of lakes, rivers and springs provide huge potential for aquaculture activities. Despite the vast and valuable fish resources in Iran, the share of fishery industries has not been desirable (0.23% of GDP and 2.7% of agriculture sector). In 2006, fish production in Iran was about 551,000 MT, of which 130,000 MT came from aquaculture and 421,000 MT was captured from the Persian Gulf, Oman Sea, and Caspian Sea. Hence, the contributions of fishing and aquaculture in Iran were 76 and 24%, respectively, compared to the world's productions of 53 and 47% (FAO FishStat, 2009).

However, to ensure the national food security and to compensate the regulatory limitations in fish caught, the Iranian Fisheries Organization (IFO), in affiliation with the Ministry of Agriculture, has embarked on policy to boost the aquaculture production of valuable species. In Iran, the sole species for cold water aquaculture is rainbow trout (*Oncorhynchus mykiss*) (IFO, 2007). Rainbow trout is one of the most important salmonid fishes cultured in fresh and brackish water in Europe, North America, and many other parts of the world. Global production of rainbow trout in 2007 was 608,787 MT, whereas Iran contributed about 9.5% of total production. In this case, Iran is known as one of the top rainbow trout producers in the world and ranked first in Asia and third in the world after Chile and Norway (FAO-FishStat, 2009). In view of the legal limitation in the fishery development in Iran and from the aspects of socio-economy, namely nutritional security (e.g. cheap animal protein source), job creation opportunity, rural poverty alleviation and potentiality of earning foreign exchange, the aquaculture industry (especially cold water trout farming) is favoured by the government and its investment could be substantial.

However, increase in population, lack of protein products, increase in the meat prices during the recent years, and low average per capita fish consumption in Iran (5.7 kg) compared to the world (16.7 kg), are some of the reasons for possible increase in the demand for fish. Productivity growth is one of the most important determinants of growth in the aquaculture capacity over time; hence, measuring productivity and technical change indices as well as investigating factors affecting them could assist in planning and policy making in the aquaculture sector. In fact, the future trends of the aquaculture sector in any country are dependent on the productivity and technical changes of the aquaculture activities. Improved productivity and technical changes can be a directing force in the development of aquaculture production as well as to be necessary to feed the human population.

Many earlier studies on productivity and efficiency in agriculture focused on crop and livestock farms by using parametric and non-parametric approaches with cross-sectional and panel data (Cinemre et al., 2006; Alemdar and Oren, 2006; Hassanpour et al., 2008). However, a few studies have addressed the issue of productivity and technical efficiency in aquaculture production (Martinez-Cordero et al., 1999; Iinuma et al., 1999; Sharma et al., 1999; Sharma and Leung, 2000; Dey et al., 2000; Chiang et al., 2004; Martinez et al., 2004; Cinemre et al., 2006; Kaliba et al., 2007; Singh, 2008; Singh et al., 2009) and also regarding the fishery industry (Squires and Reid, 2004; Tingley et al., 2005; Walden, 2006). Further, there have been quite a few economic studies on productivity in Iranian aquaculture (Khayyati and Mashoufi, 2007), but there are no such studies on total factor productivity (TFP) growth, technical progress, and socio-economic/bio-technical factors affecting them in rainbow trout farming with panel data in Iran and the world. Therefore, the purpose of this study is to measure the total factor productivity (TFP) growth of the trout aquaculture and to decompose the TFP growth into its components, namely; technical efficiency change (EFFCH) and technical change (TECHCH), at the first stage and then at the second stage, the study attempts to determine the major socio-economics and bio-technical factors that significantly influence the technical change in the trout aquaculture industry.

MATERIALS AND METHODS

Productivity change measures under DEA

For the productivity analysis, Fare et al. (1994) showed that the DEA method can be used to obtain estimates of the Malmquist total factor productivity (TFP) index numbers. In recent years, the Malmquist index has become the standard approach to productivity measurement within the non-parametric literature (Oliveira et al., 2009). This index is defined using distance functions. Distance functions allow one to describe a multi-input, multi-output production technology without the need to specify a behavioral objective such as cost minimization or profit maximization (Coelli et al., 1998). The Malmquist TFP index measures the TFP change between two data points (e.g., those of a particular firm in two adjacent time periods) by calculating the ratio of the distances of each data point relative to a common technology. Fare et al. (1994) and Grosskopf (2003) showed that to calculate the index, it is necessary to calculate the four component output distance functions, which will involve four linear programming programs for each producer in each pair of adjacent time periods. The technology and the associated distance functions are independent of the units of measurement. Following Fare et al. (1994) and Coelli et al. (1998), the final formula of the Malmquist TFP change index between the period t (the base period) and the period t+1 is as follows:

$$m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \cdot \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \cdot \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)}\right]^{1/2} \quad (1)$$

where the notation $d_o^t(x_{t+1}, y_{t+1})$ represents the distance from theperiod *t+1* observation to the period *t* technology. A value of m_o greater than one will indicate a positive TFP growth from period *t* to period *t+1* while a value less than one indicates a TFP decline.

Note that Equation (1) is in fact the geometric mean of two TFP indices where the ratio outside the brackets measures the change in the output-oriented measure of Farrell technical efficiency between period *t* and *t+1*. In other words, the technical efficiency change (or catch-up) is equivalent to the ratio of the technical efficiency in period *t+1* to the technical efficiency in period *t*. The aforementioned themes are summarized in the following simplified feature:

$$m_o = TFPCH = [EFFCH] \times [TECHCH] \quad (2)$$

The DEA-Malmquist index not only measured TFP growth but also decomposed the TFP change into technical efficiency changes (catch up with the best-practiced farms which form the frontier) and technical change (shifting of the frontier or innovation improvement) denoted as EFFCH and TECHCH, respectively. Along with this, EFFCH is also decomposed into the pure efficiency change (PECH) which is under the VRS assumption and scale efficiency change (SECH) which is relative to CRS technology. Scale efficiency change is the ratio between efficiency and pure efficiency change or simply EFFCH/PECH. In this study, one output and five inputs were used in a DEA model. The software package DEAP version 2.1 (Coelli, 1996), was used to measure TFP growth and its components for each trout farms.

Logit and tobit regression models

Some socio-economic and bio-technical factors that can either enhance or hinder trout aquaculture's technical change could be analyzed using a regression model, which is often called the limited dependent variable model, such as the logit and tobit regression models (Gujarati and Porter, 2009). Logit (logistic) regression model was employed in the form of a dummy (binary or dichotomous) regression model, which has only two possible values (e.g. yes or no), usually coded numerically as 1 or 0, respectively. When there was a panel data with annual or yearly information of decision-making units (DMUs), the model could be expanded to take into account the changes in the DMU's decision over time which in this case it was called panel logit regression. A panel logit regression model can be written as follows:

$$y_{it}^{*} = \beta' x_{it} + u_{it} \quad , \; i = 1,2,...,N \;, t = 1,2,...,T \;, u_{it} = \alpha_i + \nu_{it} \quad (3)$$

where y^{*}_{it} is an indicator variable denoting whether the progress rate of i-th DMU's technology (or innovation improvement) here, the rainbow trout farm is growing at time t, $\beta' x_{it}$ is a vector of estimated parameters and the explanatory variables, u_{it} is a composed error. This error is supposed to have two components; α_i and ν_{it}, which are assumed to be independently distributed as $\alpha_i \sim IID(0, \sigma^2_\alpha)$ and $\nu_{it} \sim IIN(0, \sigma^2_\nu)$, respectively[1].

The dependent variable takes a value of 1 if the farm technology will grow in year t and 0 otherwise. Meanwhile, the estimations can be undertaken by pooling all the years together and running a straightforward logit as the pooled logit estimation by using the conditional fixed effect logit estimation or the random effect estimation specification of the panel data logit (Wooldridge, 2002). Partial derivatives, which are very important to interpret the logit models estimation, are called the "partial effects" or "marginal effects" (Greene, 2003). In point of fact, the marginal effect (ME) is the slope of the probability curve relating k-th explanatory variable to probability of a dependent variable, holding all other explanatory variables constant. Hence, in the study, MEs indicate to reflect the change in the probability of becoming a success in the technical progress of the DMU from a unit change in the explanatory variable. Following Greene (2003), the simplified equation is shown as follows:

$$ME_{logit} = \partial E[y_{it} \mid x_{it}] / \partial x_{it} = Scale \cdot \hat{\beta} \;, Scale = e^{\beta' x_{it}} / [1 + e^{\beta' x_{it}}]^2 \quad (4)$$

Although the marginal effects (ME) of explanatory variable is not exactly equal to its estimated beta coefficients, the sign of ME or its partial derivative is the same with the sign of beta coefficient. In spite of that, in some studies, the estimated coefficients in binary logit (or probit) models are reported as the ME of explanatory variables (Drucker and Mayer, 2008; Yueh, 2009; Nassimbeni, 2001).

On the other hand, the tobit regression model was used when the dependent variable is ranged between zero and one or can be scaled to be between 0 and 100%. In other words, in this model, observations on the dependent variable are missing (or censored) if it is below (or above) a certain threshold level. Hence, some observation can be known as a censored data; that is why the model is also known as a censored regression model. When there was a panel data with information on the annual or yearly observations of decision-making units (DMUs), the model could be expanded to take into account the changes in the DMUs over time which in this case it was called panel tobit regression. A panel tobit regression model can be written as follows:

$$y^{*}_{it} = \beta' x_{it} + u_{it} \quad , \; i = 1,2,...,N \;, \quad t = 1,2,...,T \;, \quad u_{it} = \alpha_i + \nu_{it} \quad (5)$$

where y^{*}_{it} is again an indicator variable denoting the technical progress rate (innovation improvement) corresponding to the i-th DMU (fish producer) in trout farm at time t, $\beta' x_{it}$ is a vector of estimated parameters and the explanatory variables, and u_{it} is a composed error, which is assumed to have two components; α_i and ν_{it}. These are assumed to be independent and distributed as $\alpha_i \sim IID(0, \sigma_\alpha^2)$ and $\nu_{it} \sim IIN(0, \sigma^2_\nu)$, respectively (Wooldridge, 2002). The component α_i is an idiosyncratic fixed effect (which takes into account the differences in unobservable time invariant characteristics of the farms), and the random component ν_{it} is a random variable corresponding to the disturbances across i-th DMU over year t. The dependent variable (y^{*}_{it}) is the latent variable, which refers to the rate of technical progress for i^{th} DMU. It will take a value of between just a little more than 0 and 100% if the technology of trout farms grows positively in year t, whereas y^*_{it} will be exactly 0 if the technology of trout farms is zero or it is negatively grown. The tobit model parameters can provide more information on economic and policy implications through the estimation and decomposition of the marginal effects (MEs). In point of fact, the overall MEs of the tobit model could be decomposed into two distinct components: The marginal effect for the expected value of the dependent variable conditional on being uncensored, which is the effect on the probability of being above the limit, and the marginal effect for the unconditional expected value of the dependent variable, which is the effect of conditional upon being above the limit (McDonald and Moffitt, 1980). Hence, the conditional and unconditional expected values of the dependent variable (y_i) in the panel tobit model can be written, respectively as follows:

$$\text{Conditional ME}_{tobit} = \partial E[y_{it} \mid x_{it}, y \le 0] / \partial x_{it}$$

$$\text{Unconditional ME}_{tobit} = \partial E[y^*_{it} \mid x_{it}, y_{it} > 0] / \partial x_{it}$$

$$\text{Total ME}_{tobit} = \partial E[y_{it} \mid x_{it}, y_{it} \le 0] / \partial x_{it} + \partial E[y^*_{it} \mid x_{it}, y_{it} > 0] / \partial x_{it} \quad (6)$$

The estimations mentioned above can be undertaken by pooling all the years together and running a straightforward logit/tobit as the pooled logit/tobit estimation and by using a random effect estimation specification of the panel data logit/tobit (Wooldridge, 2002). A poolability test could compare the results of the two regression mentioned and allow the researcher to prefer one of them for the analysis. Thus, this study could test whether the ordinary (pooled) logit/tobit model or the random-effect (panel) logit/tobit model was preferable using the likelihood-ratio (LR) tests. At this point, the poolability tests examined the equality of logit/tobit regression variances and their estimated parameters in the sample estimation over time using other statistics, often called the “rho test”, which uses the LR test of the variances and Chi-square (X^2). The rho test $[\text{rho} = \rho = \sigma^2_v / (\sigma^2_v + \sigma^2_\infty)]$ using LR test allowed the researcher to reject the hypothesis that rho = 0, this means that the random-effect (panel), logit/tobit is preferable to the pooled logit/tobit. In addition, the researcher should test whether the rho is significantly different from zero by specifying the logit/tobit model. When the rho equals zero ($\rho = 0$), the pooled logit/tobit is preferable to the random-effect logit/tobit because it is more efficient (that is, fewer parameters need to be estimated). In order to conduct the poolability test and to estimate the models mentioned STATA software package, release 10 (StataCorp, 2007) was utilised.

Data and variables

Primary and secondary data were collected from the Iranian Fisheries Organization (IFO). In fact, this study used a panel data (the combined cross-section and time series data) on 207 rainbow trout ponds over a five-year period from 2003 to 2007 (that is, 1032 ponds in total). The data were gathered from the chosen provinces, namely; Fars, Kogiluyeh, Charmohal, Tehran and Mazandaran. The annual numbers of trout ponds for the mentioned provinces were 40, 21, 37, 48 and 61, respectively. These provinces are located in south, centre and north of Iran and reported to account for about 60% of the country’s total quantity. Notably, the reason for using the data in these selected provinces in the given period was due to the availability of the data sources as well as the homogeneity of the selected areas and climate. Since rainbow trout farms are distributed primarily in these provinces, mainly in the mountainous area with cool summers and freezing winters, homogeneity of climate conditions among studied areas was assumed. In the sample all trout farmers reared rainbow trout in simple concrete raceways in a rearing season of one year. Thus, homogenous trout aquaculture technology was assumed for all regions studied. In this study, the only output is the rainbow trout production (tons per year). Inputs included pond area (meter squares), fry (1,000 pieces per year), water flow (L/s), feed (tons per year) and labor (person-year). These factors were under the control of the trout farmers as decision making units. Rainbow trout need a regular flow of abundant cold and clean water in the ponds, with sufficient oxygen content. The farmers can regulate the rate of water flow into their concrete raceway ponds or the trout farms during the rearing season. Because of the different climate conditions during different seasons of the year and water temperature changes, as usual, the rainbow trout fry are not stocked into rearing ponds by the trout farmers. In Iran, the eyed eggs and fry are mainly produced by the governmental main hatchery and aquaculture research institutes, and then the required fry are delivered to the trout culture sites by a private transport sector. Some farmers have small hatchery units inside their trout farms in order to produce eyed eggs and fish fry.

All the explanatory variables, namely the socio-economic/bio-technical variables and farm characteristics, used in this study are referred to as environmental factors[1], which may have influenced the technical change (innovation) in the trout aquaculture industry. In this study, a number of environmental factors (including socio-economic variables) were considered in the analysis of the factors which are affecting the technical change in the trout aquaculture. Based on the raw data obtained from the respondents through trout farms, there were a total of 18 environmental factors. These variables were expected as responsible for the rising/declining technical change (innovation) in the trout aquaculture in Iran. These variables were generally categorized into five major groups or characteristics: Water, personnel, fry, farm and access to government facilities. The description and classification of the variables are as follows: Variables associated with water use characteristics that consist of six variables. These variables include water used temperature average in each production period in terms of degree in Celsius (°C) (WTTEM), water temperature more than the sample average, which is a dummy variable (WTEMMA), with suitable water temperature average (that is, between 13 to 18°C) according to the suggestion of aqua specialists literatured[2], and a dummy variable (SWTTM), flow rate or water discharge imported to each pond (FLOWRT), a dummy variable for the river as water used source (WRSORI), and another dummy variable for the spring as water used source (WRSOSP). Three variables are associated with the operators’ personal characteristics. These variables include education level of the operators (EDULOP), number of illiterate labours (NOILLB), and the number of lower diploma labours (NOLWDL). Three variables are associated with the characteristics of fry (fish larva). These variables consist a number of fry per unit area (NOFYPU), fry weight average in terms of gram (FYWEIA), and a dummy variable for fry supply source or hatchery unit place (on-farm or off-farm) (FYSOFM). Three variables are associated with the characteristics of farm (pond). These variables consist of pond area which more than sample average as a dummy variable (POAMAV), fish production per area unit in terms of kg/m^2 (FISHPR), and feed quantity in terms of kg/m^2 (FEEDQN). Three variables associated with access to some government facilities,

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[1] The term “environmental variables” is usually used to describe factors which could influence the productivity and efficiency of a decision-making unit (Coelli *et al*., 1998).

[2] The suitable water temperature range for feeding and growth is 13-18°C in rainbow trout farming (Klontz, 1991).

Table 1. Annual mean TFP change and its decomposition in trout farming, 2003-2007.

Year	EFFCH		PECH		SECH		TECHCH		TFPCH	
	Index	(%)	Index	(%)	Index	(%)	Index	(%)	Index	(%)
2003	1	0	1	0	1	0	1	0	1	0
2004	1.289	28.9	1.236	23.6	1.043	4.3	0.830	-17	1.069	6.9
2005	1.026	2.6	0.999	-0.1	1.027	2.7	0.983	-1.7	1.009	0.9
2006	1.088	8.8	1.079	7.9	1.008	0.8	0.976	-2.4	1.062	6.2
2007	0.993	-0.7	0.966	-3.4	1.028	2.8	1.016	1.6	1.009	0.9
Mean	1.093	9.3	1.065	6.5	1.026	2.6	0.948	-5.2	1.037	3.7

Source: Survey, 2009.

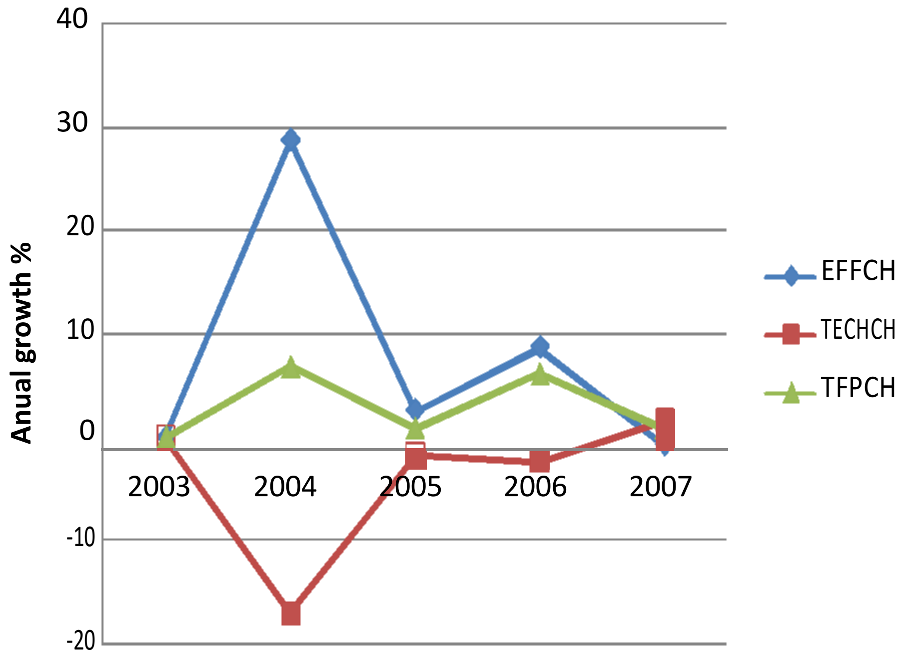

Figure 1. Trends of TFP growth and its decomposition in trout aquaculture, 2003-2007.

namely insurance coverage (INSCOV), operators' attendance in workshop more than two times (ATWKM2), and governmental tenure (TENGOV), as previously mentioned are dummy variables.

RESULTS AND DISCUSSION

Productivity changes of rainbow trout aquaculture

Table 1 shows the results of the Malmquist DEA analysis, the total factor productivity change (TFPCH), technical efficiency change (EFFCH), and technical change (TECHCH) or innovation improvement. A value of greater than one implies a positive TFP growth of DMU for a sample of trout farms, and this is denoted by a percentage greater than zero. Meanwhile, a value below one indicates a negative TFP growth, which is computed by a percentage below zero. As shown in Table 1 and Figure 1, the TFPCH and EFFCH of trout farming increased at an average annual rate of 3.7 and 9.3% respectively over the stated period. Moreover, the rate of technical change (TECHCH) of trout farming was found to decrease at an average annual negative rate of -5.2% per year. Thus, the TFP growth was positive at an average annual rate of 3.7%, but there was no technical progress or innovation improvement on trout farming industries over the study period. The dynamic analyses of productivity components showed that they fluctuated during the period, with a sharp increment and decline in the EFFCH before and after 2004. Meanwhile, there were sharp decline and increment in TECHCH in the same year (Figure 1).

In addition, the EFFCH was decomposed into pure

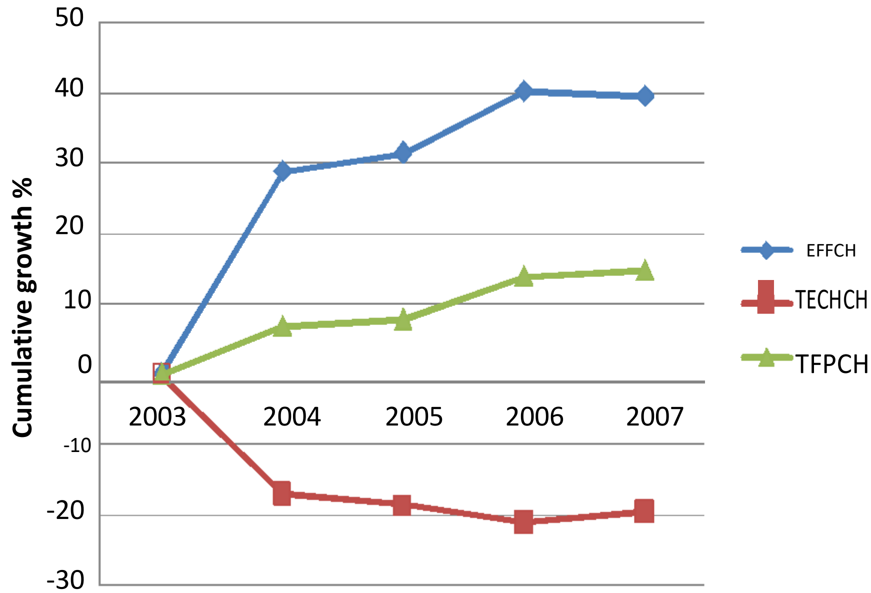

Figure 2. Trends of cumulative TFP growth and its decomposition in trout aquaculture, 2003 to 2007.

efficiency change (PECH) and scale efficiency change (SECH) which represent managerial efficiency change and efficiency change related to the trout farm scale, respectively. The trend of the EFFCH as well as EFFCH's decomposed components indicated that the variation of the PECH or managerial efficiency of trout farms considerably affected the magnitude of the EFFCH more than the effect from SECH magnitude as shown in Table 1. This indicated that most rainbow trout farmers could become more technically efficient by adjusting the inputs used, rather than by adjusting the scale of operation. The mean of all the components of productivity growth as shown Table 1, except technical progress (or innovation or frontier shift), were positive rates in the trout aquaculture industry. Thus, the technical change (TECHCH) was absent in trout aquaculture industry and the technical efficiency change (EFFCH) as well as its decomposition (that is, PECH and SECH) were found to be the sources for TFP change. In term of the trends in the cumulative TFP growth and its decomposition, on the other hand, the EFFCH seemed to contradict with the TECHCH (innovation or adoption of improved techniques) over the study period. However, there were relatively stable changes from 2006 onwards (Figure 2). Therefore, the growth in the productivity of trout farming during 2003 to 2007 was entirely due to the change in the cumulative technical efficiency (catch up or managerial improvement). In other words, the TFP growth of trout farming in the aquaculture sector was contributed only by EFFCH rather than TECHCH or innovation improvement. This may be due to a lack of direct investment (domestic and foreign) the Iranian agriculture sector, as well as the capital intensive farming practices and the lack of new technology knowledge required for aquaculture. This finding is supported by Saleh et al. (2008) and Mousavi-Haghighi et al. (2008).

Panel tobit regressions analyses

The panel tobit model was used to assess the effect of selected environmental variables (as the explanatory variables) on the TFP growth index of trout farms (as the dependent or latent variable). In the beginning, the rho (ρ) test and the Chi-square (X^2) were tested in order to test poolability of the panel data. The results gathered from the poolability test showed that the hypothesis ρ = 0 has failed to reject the regression function related to the TFP Malmquist index. Hence, both the pooled logit and tobit were preferable in the random-effects models for TECHCH function (Table 3). Therefore, the pooled logit and pooled tobit preferred models were used to determine the extent to which selected various environmental variables of the technical change index of the trout farms.

Based on the measure obtained from the DEA-Malmquist analysis (that is, the first stage), TECHCH (as latent variable) was censored at the upper and lower limits, with values equivalent to zero and 100%, respectively. This means that technical change index is supposed to be observed for trout farms with any positive change, but it is not observed for those with zero change (or changeless) or any negative change. The estimation results, including the models' significance, estimated

Table 2. Estimation results of pooled logit and tobit models on technical change, 2003 to 2007.

Variable	Pooled logit model			Pooled tobit model				
	Estimated coefficient	t-value	Marginal effect	Estimated coefficient	t-value	Marginal effect		
						Cond.	Uncond.	Total
FYWEIA	-.0073128	-1.15	-o.0018023	-0.1054397	-1.43	-0.0335434	-0.0435271	-0.07707
FLOWRT	0.0011668	2.79***	0.0002876	0.0089542	1.97**	0.0028486	0.0036964	0.006545
WTTEM	0.0668656	1.21	0.01648	0.318399	0.52	0.101292	0.1314399	0.232732
EDULOP	0.0546769	1.06	0.0134759	1.172979	1.99**	0.3731588	0.4842236	0.857382
NOILLB	-0.1056377	-1.45	-0.026036	0.494888	0.65	0.1574383	0.2042972	0.361736
NOLWDL	-0.0629593	-1.49	-0.0155172	-0.3219275	-0.68	-0.1024145	-0.1328965	-0.23531
ATWKM2	0.8760009	5.69***	0.2123529	7.82161	4.48***	2.485505	3.216909	5.702414
POAMAV	-0.3377374	-1.67*	-0.0823141	-4.54077	-1.98**	-1.408622	-1.800299	-3.20892
WTEMMA	1.870121	2.64***	0.0823141	14.14283	1.79**	4.61682	6.033048	10.64987
INSCOV	-0.7974146	-5.24***	-0.1925308	-7.464036	-4.22***	-2.339313	-3.004631	-5.34394
TENGOV	-0.260882	-1.56	-0.0637486	-3.767187	-1.99**	-1.171819	-1.500377	-2.6722
FYSOFM	0.352811	2.10**	0.0874483	2.636986	1.40	.8543805	1.119398	1.973779
WRSORI	-0.2032945	-0.97	-0.0498141	-1.999628	-0.82	-0.6291908	-0.8112989	-1.44049
WRSOSP	0.1571202	0.75	0.0386954	3.081594	1.29	.9794319	1.269893	2.249325
FISHPR	.0175137	1.24	0.0043165	.5515554	3.44***	.1754658	.2276904	0.403156
NOFYPU	-0.0037487	-2.04**	-0.0009239	-.0544417	-2.60***	-.0173195	-.0224744	-0.03979
FEEDQN	0.0021953	0.26	0.0005411	-.0863386	-0.90	-.0274668	-.0356419	-0.06311
SWTTM	1.549424	2.59***	0.3628889	9.724492	1.46	3.080363	3.975553	7.055916
Constant	-3.331232	-2.74***		-32.44985	-2.40***			
Wald Chi2 (18)		99.05***				105.61***		
Loglikelihood		-654.23836				-2393.664		
Left-censored obs.		0				571		
Number of obs.		1035				1035		

*, ** and *** denotes, respectively, significance at the 10, 5 and 1% level. Source: Survey, 2009.

coefficients, and marginal effects from both the pooled logit and tobit models on DEA-Malmquist TECHCH index (innovation improvement) were reported in Table 2.

Based on this result, both the estimated pooled logit and tobit models were found to be statistically significant with a Log-likelihood ratio test ($P < 0.01$) and a Wald-Chi^2 at 1% level of significance, indicating a joint significance of all environmental variables' coefficient estimates in the TECHCH function. In other words, the hypothesis postulating that all environmental variables jointly included in the model had no influence on the TECHCH (null hypothesis) of trout farms could be rejected at 1% level of significance. These test also implied that environmental (independent) variables selected could be used to explain the variations in the latent variable in both pooled logit and tobit models. Furthermore, the estimated coefficients were tested using the standard errors and t-values in the TECHCH function. The results

Table 3. Poolability test results for panel tobit and panel logit models on TECHCH function of the trout farming.

Function	Model	Rho (ρ)	Std. Er. P	X^2	Sig. X^2	Preferable model
TECHCH	Logit	3.02e-07	7.05e-06	6.0e-05	0.497	Pooled
	Tobit	3.06e-33	7.73e-18	0.00	1.00	Pooled

Source: Survey, 2009.

and interpretation were focused in the statistically significant coefficients. Note that in the estimated models shown in Table 2, a positive sign on the statistically significant parameter estimate of one variable indicates the likelihood of the latent variable increasing, holding other variables constant, and vice versa.

In addition, the estimated coefficients could be converted into a set of marginal effects (MEs) on the probability of recording a positive technical change in trout farming. Therefore, the significant key factors affecting technical change could be ranked based on the analysis of the marginal effects, which are further elaborated in this study. On the whole, and based on the results presented in Tables 2, it could therefore be concluded that there is a consistency between the results of the factors affecting the technical change derived using both the logit and tobit models. This means all the statistically significant signs in the pooled logit regression were quite similar to the pooled tobit regression.

As can be seen in Table 2, the estimation results revealed that certain environmental variables, such as flow rate or water discharge in terms of litter per seconds (FLOWRT), the education level of the operators (EDULOP), operators' attendance in workshop more than two times (ATWKM2), water temperature more than the sample average (WTEMMA), fry supply source (hatchery) inside the farm (FYSOFM), quantity of fish production in terms of kg per square metre (FISHPR), and suitable water temperature (that is, 13 to 18°C) (SWTTM) positively affected the probability of increase in the TECHCH level, whereas other variables like the pond area which more than sample average (POAMAV), government insurance coverage (INSCOV), and governmental tenure (TENGOV), and number of fry per square metre (NOFYPU), were found to have negatively affected the probability of increase in the TECHCH level in trout aquaculture industry. The p-value for all the variables estimates previously discussed were lower than 0.05 level of significance, indicating that the variable estimates were statistically significant. Therefore, it was inferred that the eleven factors included in the model (namely FLOWRT, EDULOP, ATWKM2, WTEMMA, FYSOFM, FISHPR, SWTTM, POAMAV, INSCOV, TENGOV, and NOFYPU) were key factors that affected the TECHCH level or innovation improvement of trout farming in Iran.

Main factors affecting TECHCH

Based on the amounts of the logit marginal effects (MEs) and tobit MEs in Table 2, the main factors affecting TECHCH as well as the intensity and the sign of these effects on trout farms are graphically illustrated. Figures 3 and 4 rank the statistically significant factors affecting TECHCH based on the amount of logit ME and tobit ME, respectively. In Figure 2, SWTTM is shown to have the largest positive value of ME, followed by ATWKM2, FYSOFM, WTEMMA, and FLOWRT, respectively. Meanwhile, INSCOV has the largest negative value of ME, and this is followed by POAMAV, and NOFYPU, respectively. The intensive positive influence of SWTTM revealed that trout farms which have suitable water temperature (that is, 13 to 18°C) tended to have more technical progress or innovation improvement. From the biological aspect, water temperature is one of the most important factors in trout farming (Bardach et al., 1972; Klontz, 1991; Molony, 2001). It is important to highlight that rainbow trouts need a regular flow of abundant cold and clean water in the ponds, with sufficient oxygen content. Apparently, cold water holds more oxygen than warm water; however, very cold water is not suitable for rearing rainbow trout. For this, Klontz (1991) suggested that the most suitable water temperature range for feeding and growth in trout farming is 13 to 18°C.

Similarly, the relatively intensive positive impact of ATWKM2 indicated that trout farmers attending workshops more than two times would have more TECHCH. The main reason is that the extension and training activities could contribute to the human resource development in the trout aquaculture sector and consequently, the managerial and innovation improvement in trout farming. Similar results were also suggested by Kaliba and Engle (2006) on catfish farms in Arkansas and by Cinemre et al. (2006) on trout farms in Turkey.

The dummy variable of FYSOFM was found to positively affect TECHCH, and this indicated that TECHCH increased where there hatchery units are available in respective trout farms. This infers that the innovation expansion increase when each trout farm has its own hatchery unit. This is also related to transportation of fry. The rainbow trout fry are not usually stocked into rearing ponds by trout farmers during the various climatic

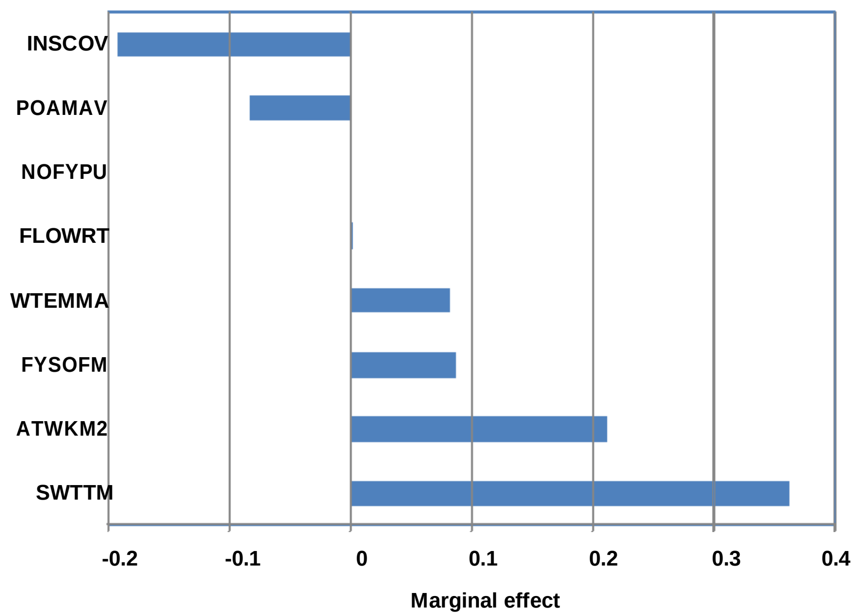

Figure 3. Significant factors affecting TECHCH based on the MEs of the pooled logit in trout farming.

conditions during the different seasons of the year. Instead, eyed eggs and fry are mainly produced by the main hatchery and aquaculture research institutes owned by the government, and the required fry and fingerling are delivered to the trout culture sites by private transport operators. Generally, fry is usually transported in a crowded condition which can deteriorate fish's health. Finally, FLOWRT was found to positively influence TECHCH trivial indicating an increase in TECHCH when the flow rate imported to trout farm is higher. A similar finding was noted by Zarranezhad and Rezaei (2004) in the trout farming sector in Iran.

On the other hand, the dummy variable (insurance coverage as a safeguard against some kinds of production losses) (INSCOV) was unexpectedly found as the most negatively related to the probability to increase the technical progress of trout farming. In terms of value, the insurance coverage has the largest negative value of ME as compared to other explanatory variables. Hence, in the trout aquaculture industry, insurance coverage inversely affects the innovation improvement or adoption of new techniques over time. Unfortunately, relevant literature which could explain the causes of the aforementioned fact is rather limited. Insurance paid via direct cash payment, the absence of fish production incentives, and the lack of sufficient infrastructure for most aquaculture services could be among the causes. This finding is in agreement with the study of Abbasi (2007) in which insurance coverage was not positively found to affect the technical progress or shift the production frontier in Iran's animal husbandry. Furthermore, one of the important characteristics of trout farms is the size of pond area. Nonetheless, on contrary to the researcher's expectation, there was a negative intense relationship between the dummy variable of the pond area size (POAMAV) and technical progress (TECHCH), which is one of the main components for the TFP growth. The high negative amount of ME confirms this claim and this means that the trout farmers with pond area size larger than the average sample (that is, 2500 m^2) are inversely related to the probability to improve innovation. The main reason for this is the ownership structure of the big trout farms in Iran. However, this finding contradicts with that of Wetengere (2009) and Barmon et al. (2007) who showed that fish farmers with higher fish farm areas were more likely to adopt new technology than those with smaller fish farm areas.

Finally, NOFYPU was shown to have affected the TECHCH negatively trivial, showing that increasing the number of fry per square metre could lead to a lower TECHCH in trout farming. This result could be due to the existence of a particular disease when there is excessive number of fry and a high mortality rate in rainbow trout fry during the initial period of trout farming. Therefore, an excessive use of fry in trout ponds might lead to a major decrease in the trout production and reduce the productivity growth as well. A similar finding was noted by Zarranezhad and Rezaei (2004) and Khayyati and Mashoufi (2007) in the trout farming sector in Iran.

In addition, considering the amounts of the tobit MEs, the results of the logit MEs above were shown to be similar to the results gathered for the tobit shown in Figure 4. Although the tobit analysis further provide factors affecting TECHCH and extra information on the

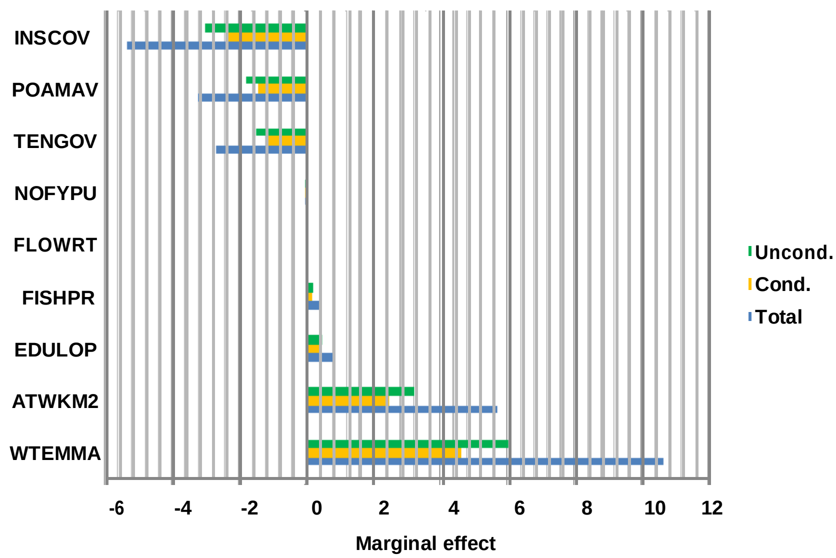

Figure 4. Significant factors affecting TECHCH based on the MEs of the pooled tobit in trout farming.

components of ME as compared to the logit analysis, it reached almost the same conclusion in terms of the main factors affecting technical progress. This means that the main positive (negative) factors affecting TECHCH, which were ranked based on the logit MEs, are similar to the main positive (negative) factors that affected TECHCH which were ranked based on the tobit MEs. However, further results shown in Figure 4 are the expected positive influence of the educational level of the operators (EDULOP), and on the contrary to the expectation of this study, the negative influence of governmental tenure (TENGOV) on technical progress. EDULOP is positively related to the probability to increase the TECHCH or innovation improvement. In other words, a trout operator with higher education level is more likely to adopt the best available technology than those with low education level. The main reason is that education increases fish farmers' ability in and knowledge of trout production. This finding is in agreement with that of Wetengere (2009) who showed that a fish farmer's level of education increases the probability to adopt better fish farming technology.

Furthermore, the dummy variable of governmental tenure (TENGOV), in pooled tobit model, was found to affect technical change, so that it was negatively related to the probability to improve innovation or TECHCH. In other words, the tenure under government (that is, public companies or cooperatives) contributed to the decline in technical progress or adoption of new techniques compared to the operator-owned farms. This might be due to a deficient management in the existing government structure on public/cooperative farms. This result corroborated the results of Kaliba and Engle (2006) and Cinemre et al. (2006) who suggested that fish farmers with owned farms were more likely to be efficient than other farmers.

Therefore, higher TECHCH or innovation improvement in trout farms are likely to be found where there are the lower education level of operators as well as the tenure under government (that is, public company or cooperative) that leads to the decline in technical progress or adoption of new techniques in trout farming. According to the survey done, about 29% of trout farms were under governmental tenure, while the rest (71%) were privately owned farms.

Apart from this, the remarkable information depicted in Figure 4 is the evaluation on the contribution of ME's two distinct components (that is, unconditional[1] and conditional[2]) which are related to the influence of each explanatory variable on the dependent variable (TECHCH). For example, as shown in Table 2, the extent of ME associated with ATWKM2 was 5.702, of which the extent of 2.485 (43.6%) and 3.217 (56.4%) were obtained from the conditional ME and unconditional ME, respectively. In other words, percentages of 43.6 and 56.4 are the proportions of the censored and uncensored observations, respectively. Therefore, it could approximately be concluded that attending workshop (ATWKM2) for those trout farmers with censored (that is, This interesting result could also be extended to other main variables that affect TECHCH such as WTEMMA, EDULOP, INSCOV, and TENGOV, since their censored

[1] Unconditional ME equivalent to the ME for the unconditional expected value of the dependent variable on being uncensored (i.e. those which have positive TFP growth).

[2] Conditional ME equivalent to the conditional expected value of the dependent variable on being censored (i.e. the ones which do not have positive TFP growth).

observation proportion was about 43 to 44%.

CONCLUSIONS AND RECOMMENDATIONS

In the study, a two-stage estimation procedure for analyzing factors influencing technical change (TECHCH) in the aquaculture industry was applied. The first stage measured the Malmquist TFP growth and its major components (that is, EFFCH and TECHCH), while an econometric model, such as the logit and tobit regression models were performed in the second stage so as to ascertain the factors that might have impacts on the TECHCH. Both the pooled-tobit and pooled-logit estimators, which were adopted in the study, were used and compared to ascertain the determinants of TECHCH in trout aquaculture. The following are the empirical findings and implications that can assist policy makers to enhance the rate of TECHCH in trout aquaculture sector. The average annual TFP growth of trout industry during the period 2003 to 2007 was 3.7%, representing a figure substantially lower than the targeted annual GDP growth (8%) over the same period of time (CBI, 2009). On the other hand, the TFP growth of trout farming in the aquaculture sector is considerably formed from EFFCH or managerial improvement rather than TECHCH or innovation improvement. This means that many trout farmers have not been adopting the best available technology. This also means that Iran still has a room to improve the TFP growth in the trout aquaculture, and this can be done by shifting its production frontier through improving innovation and development of new technologies. Since the main problem faced by the aquaculture is the lack of technology (innovation) and this has also been identified as the major constraint faced in developing rainbow trout farming, there is an urgent need to modernize the current technology and expedite the transfer of new technologies. This can help boost the quantity and quality of trout production at various seasons of the year, which in turn, significantly enhance the productivity growth.

In the second stage of the study, the rate of technical changes estimated, which is the major source of TFP growth, were then regressed on the some socio-economics and bio-technical factors that are likely to lead to boost innovation in the trout aquaculture industry. The results proved that the water temperature is the most important environmental factors to boost the technical change or innovation improvement in trout farming. The strong positive impacts of suitable water temperature signified that trout farms with suitable water temperature (that is, 13 to 18°C) tended to have more technical progress or innovation improvement. These points should be taken into consideration by government (that is, Iranian Fisheries Organization or IFO) in topology and selecting suitable location. The survey indicated almost half (47.3%) of the trout farms sampled did not have suitable water temperature in the production period; hence, further examination should be carried out to find methods which can be used to improve water temperature conditions at trout farms. Supplying a complete technical package to improve and regulate water temperature at trout farms may stimulate the adoption of improved technology and consequently, the TFP growth.

Meanwhile, the training workshop on trout aquaculture is one of the most profitable government facilities to enhance the rate of technology, which is one of the main components for the TFP growth of trout farms. Therefore, continuing and developing training courses by IFO, which is the sole agency performing aquaculture extension and fish farmer training activities can contribute to the human resource development in the trout aquaculture sector and consequently, the managerial and innovation improvement in trout farming. However, the IFO's future programmes for aquaculture training and extension should focus more on the improvement of new technology in the trout aquaculture. Furthermore, such training workshops targeted at improving innovation for trout farms could further accelerate the rate of technical progress or the adoption of technology which has not been observed and delayed in the trout aquaculture industry in the recent years.

Furthermore, the results revealed that the trout operators with higher education level were more likely to adopt the best available technology than those with low education level. This can provide valuable information for the government to make strategic decisions at farm and planning levels; these include enhancing the education level of the rainbow trout operators to enhance the TECHCH and consequently, the trout farmers' TFP growth. It is important to emphasize that the development of trout aquaculture will not succeed without highly educated personnel. Finally, the results revealed that the existence of fry supply source (hatchery) inside the trout farm, positively affected the TECHCH, indicating that the rate of technical change or innovation improvement increases when there are hatchery units available at the trout farms. Hence, future aquaculture planning should include having or providing the rainbow trout hatchery units inside the farms.

On the other hand, the results proved that the governmental insurance coverage is the most important environmental factors to hinder the technical change or innovation improvement in trout farming. This means that the insurance coverage inversely affected the innovation improvement or adoption of new techniques over time. Moreover, the results showed that the tenure under government via creating trout farming cooperatives and public trout company contributed to the decline in technical progress or adoption of new techniques compared to the operator-owned farms. Therefore, it seems that the activities and social facilities provided by the government for the development of trout aquaculture, such as the governmental insurance coverage and the government tenure (that is, public companies or cooperatives), were found to be non-profitable for the technical progress and consequently, productivity growth. As a result, for the current insurance policy, the government should replace it with a more appropriate instrument such as non-cash payment (payment in kind) instead of cash payment when production fails. Under the payment in this programme, trout farmers can receive incentives when they record increased productions. In addition, the government also should improve the existing managerial structure on the public/cooperative trout farms. On contrary to the expectation, the results of the study claimed that the trout farmers with pond area size larger than the average sample (that is, 2500 m^2) are inversely related to the probability to adopt new technology or improvement innovation. Hence, there is an urgent need to study and reform the ownership structure of the big trout farms in Iran. Finally, the results asserted that an excessive use of fry in trout ponds leaded to reduce the technical progress and consequently, productivity growth. Obviously, the extension programs respect to adjust the required inputs use and water quality for rainbow trout farms can stimulate the adoption of improved technologies. Furthermore, there is a need for the government (IFO) to intervene, guide and coordinate the various actions previously mentioned including adopting the newest and latest technologies and allowing developed countries to invest in trout aquaculture in the country. Hence, IFO will not only have to undertake this task by learning from the more experienced developed countries with modern technology in trout aquaculture and getting the benefits from the global information technologies, but it also needs to open the country up for more foreign direct investment (FDI) in the trout aquaculture sector in Iran. Therefore, the government's intervention in providing more incentives to attract more FDI will contribute to the development of modern technologies and managerial know-how in the trout aquaculture industry in Iran.

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