Jin H, Xiang L, Chen F, Zhu W. The diffusion path and influencing factors of shrimp farming technology. *Israeli Journal of Aquaculture - Bamidgeh*. 2024;76(3):22-35. doi:10.46989/001c.120489

Original Research Articles

The diffusion path and influencing factors of shrimp farming technology

Hongtao Jin[1], Lele Xiang[1a], Fang Chen[1b], Wenjun Zhu[1c]

[1] College of Economics and Management, Shanghai Ocean University

Keywords: Shrimp farming, Overall efficiency, Technology diffusion, Social network

https://doi.org/10.46989/001c.120489

Israeli Journal of Aquaculture - Bamidgeh

Vol. 76, Issue 3, 2024

Aquatic products have played an increasingly important role in residents' diets, with improved production capacity and living standards in recent years. Accelerating the organic diffusion of aquaculture technology is an effective way to increase production. Taking the example of South American white shrimp aquaculture, this article combines carbon emissions and aquaculture cost benefits. By using data from South American white shrimp aquaculture in Hebei, Shandong, and Jiangsu Province in China from 2016 to 2021, the article innovatively considers aquaculture cycle carbon emissions as non-expected output, constructs a non-expected SBM-DEA super-efficiency model to evaluate the comprehensive efficiency of two aquaculture technologies, and analyzes the influencing factors of the diffusion of shrimp culture technology through case studies. The research results show that the comprehensive efficiency of factory-based aquaculture technology is generally better than pond-based aquaculture, but carbon emissions are higher in the factory model. The main factors affecting the diffusion of factory-based technology are policy support, social networks, farmers' own situations, and technological attributes.

INTRODUCTION

In recent years, with changes in the diet of Chinese residents, the demand for aquatic products has significantly increased.[1] With the development of the offshore fishing industry and overfishing, the fishing resources in China's coastal waters are gradually depleted, and the aquaculture industry has begun to develop rapidly in China.[2] The aquaculture industry in China has begun to develop rapidly. With years of development and innovation, China has now become the world's largest fishing nation: since 1989, China has ranked first in the world in terms of aquatic product production for 35 consecutive years. China is also the only country in the world where aquaculture production exceeds fishing production. In 2022, China's aquaculture production accounted for 63.24% of the world's production, holding a Leading position in various species such as shrimp and fish.

However, there are many problems and significant room for improvement in China's aquaculture industry. Firstly, the mechanization and automation levels in Chinese aquaculture are low, with many farming processes still relying on manual labor. Additionally, there is a lack of emphasis on water treatment, and the application of water treatment and circulation systems is limited. Secondly, there is a prevalence of poor-quality seedlings due to unscientific breeding practices, resulting in low survival rates and yields and even mass mortality. Lastly, many farmers still use traditional and outdated management practices, such as feeding animals indiscriminately, using drugs blindly, and neglecting ecological impacts. These issues can be attributed to the fact that some aquaculture technologies are still in a backward stage. Therefore, promoting technological progress and upgrading the aquaculture industry is a pressing issue. Technology diffusion is a crucial indicator of successful innovation,[3] and China's low agricultural technology conversion rate has become a major obstacle to agricultural modernization. Thus, promoting the diffusion of aquaculture technologies is an important pathway to drive industry advancement and progress.

As the largest species in global aquaculture production, the whiteleg shrimp from South America holds a significant position in the aquaculture industry and is one of the representative species in aquaculture. According to reports from the Food and Agriculture Organization of the United Na-

a a Lele Xiang contributed equally to this work and was considered the first co-author.

b b Corresponding author, Fang Chen, e-mail: m21070299@st.shou.edu.cn; Tel: +86-1786-051-9231.

c c Corresponding author, Wenjun Zhu, e-mail: 623410083@qq.com; Tel: +86-1326-251-6276.

tions (FAO) and the "China Fishery Statistical Yearbook", from 2010 to 2022, the global production of whiteleg shrimp increased by 145.28%. In 2022, China's total aquaculture production reached 2.0986 million tons, accounting for 30.64% of crustacean aquaculture. The main countries globally cultivating whiteleg shrimp include China, Ecuador, Vietnam, India, Thailand, Indonesia, and Mexico. These seven major producing countries collectively produced 5.3848 million tons of whiteleg shrimp in 2022, accounting for 82.84% of the world's aquaculture production. As the largest producer, China's whiteleg shrimp production has steadily ranked first in the world in recent years. In 2016, the total aquaculture production reached 1.6722 million tons, accounting for 40.24% of global production. In 2022, the total aquaculture production accounted for 32.29% of global production[1]. However, due to high demand, there is a need for significant imports. In 2022, China imported 0.818 million tons of whiteleg shrimp, reaching a historical high and surpassing the United States for the first time to become the world's largest importer. Against the backdrop of building a new development pattern with domestic circulation as the main focus, effectively increasing shrimp aquaculture production to meet domestic consumption needs has become an urgent issue to address.

In terms of the diffusion of agricultural technology, scholars have mainly conducted research from two aspects: diffusion pathways and influencing factors. For example, Li et al.[4] and Yang et al.[5] have respectively studied the dissemination of ecological technology and environmental protection technology, finding that social learning has a positive impact on the diffusion of agricultural technology. The difference lies in that Li et al. considered that technological differences would affect the positive role of social learning in the diffusion of technology, while Yang et al. considered that the marginal effects of age, education level, and operating scale are also different. Asmaa et al.[6] concluded from their study on feed agriculture technology in Iraq's Nineveh Province that training for producers and the lack of consultant funding are the main obstacles to the diffusion of feed agriculture technology. Gong[7] through empirical analysis of county-level agricultural panel data in China from 1985 to 2015, found that agricultural technology dissemination decreases with the expansion of resource endowment, geographical distance, and administrative jurisdiction, showing a "stronger get stronger, weaker get weaker" situation. Wang[8] and Gabriel[9] through simulations of the diffusion level of agricultural water-saving technology under government influence, respectively concluded that the government and peer effects have a positive impact on the adoption of water-saving technology. Yu et al.[10] simulated agricultural technology diffusion from the perspective of social networks. They found that individual learning positively affects technology diffusion, while social effects hurt it. The average number of farmers who communicate with each other is a game between the two. Li et al.[11] found through empirical analysis that the social network of farmers and subjective norms, their understanding of Taiwan's agriculture, the characteristics of Taiwan's agriculture and its technical services, and basic conditions have a significant positive impact on the diffusion of orchid technology.

In terms of research subjects, scholars mainly focus on the diffusion of agricultural technology in the fields of crop cultivation and animal husbandry, such as vegetables, rice, fruits, flowers, and pig farming. For example, Xie[12] found through research on the diffusion of Internet of Things technology among large vegetable growers that individual risk attitudes, farm size, distance to trading markets, and post-adoption benefits all have a positive impact on the diffusion of Internet of Things technology. Li et al.[13] pointed out through data regression and analysis of new potato planting technologies that farmers' awareness of technology is a middle-level factor influencing technology diffusion, while educational level, organizational level, and family structure are deep-level factors. Kuang,[14] using pig farming as an example, analyzed the relationship between social networks and agricultural technology diffusion, suggesting that social networks positively impact technology diffusion. At the same time, social networks serve as the foundation and pathway for technology diffusion. Li et al.[15,16] research on orchid technology in the Guangdong-Taiwan Agricultural Cooperation Experimental Zone from 3 dimensions suggests that technology diffusion is more prevalent in core orchid farms and less so in peripheral ones and that a "government and market" diffusion mechanism has gradually emerged from the "clan and market" diffusion mechanism.

Currently, there is not much research on the diffusion of aquaculture technology compared to agricultural technology diffusion. Similar to other agricultural technology diffusion, scholars mainly focus on factors influencing advanced aquaculture technology and discuss methods to improve the level of technology diffusion. Yari et al.[17] considered that discussing innovation in aquaculture technology without considering the viewpoints and voices of various stakeholders may lead to the ineffectiveness or even negative consequences of related policies. Kodjo et al.[18] and Obiero et al.[19] their studies on shrimp-crab polyculture technology in Anhui Province, China, and fish farmers in Nigeria found that the education level of local farmers, insurance policies, technology promotion, and government policies influence the level of technology diffusion.

Through the summary of research:(1) At present, scholars attach great importance to the diffusion of agricultural technology, while aquaculture technology is not the focus of academic and policy research. However, the aquaculture industry is obviously different from the traditional planting and breeding industry, which has higher water, capital, and technology requirements. At the same time, it is greatly affected by the stability of the policy. The technology dif-

1 The data is sourced from FAO and China Fisheries Statistical Yearbook

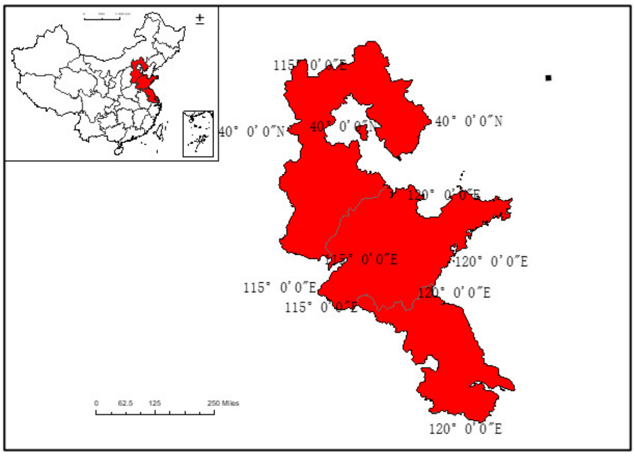

Figure 1. Distribution map of data source regions

fusion path and influencing factors are also different, so it is more necessary to carry out an in-depth analysis. (2) At present, scholars' research on aquatic technology diffusion mainly focuses on policy formulation and influencing factors and lacks overall tracking and analysis of its diffusion path. On the one hand, this paper takes Penaeus vannamei breeding as the research object innovatively takes the carbon emission of aquaculture as the unexpected output and uses the unexpected super efficiency SBM model to analyze and compare the two breeding technologies to determine the more advanced breeding technology. On the other hand, this paper analyzes the path and influencing factors of aquaculture technology diffusion from the social network perspective combined with field research and case analysis and conducts relevant discussions and suggestions.

MATERIALS AND METHODS

DATA SOURCES

The research data in this article comes from the industrial economic team of the National Shrimp and Crab Industrial Technology System. From 2016 to 2022, it researched the main production areas of shrimp farming in the Bohai Rim and the Yangtze River Delta, as shown in **Figure 1**. The reasons for selecting this region are as follows:

First, Shandong Province is the largest province in China for the farming of Penaeus vannamei, and it is also the province with the highest farming output of Penaeus vannamei in northern China. By 2020, the farming area of Penaeus vannamei in Shandong Province reached 71844 hectares, nearly twice that of Guangdong Province, which ranks second. Meanwhile, the local agricultural department is very supportive of the Penaeus vannamei farming industry, which has a very representative status. Second, the research stations in the Bohai Bay and Yangtze River Delta areas have cooperated closely with our school and the research group's teachers. The research group also frequently conducts field research and interviews there. Therefore, conducting field research and investigation in these areas can obtain local assistance and guidance, greatly reducing the investigation's difficulty and the farmers' resistance and improving the authenticity and accuracy of the investigation results. Finally, although the output of Penaeus vannamei in the Pearl River Delta region ranks first nationwide and is very meaningful for research, it mainly adopts the high-position pond farming mode. At the same time, this study mainly focuses on investigating and discussing pond farming and factory farming. At the same time, the research group has encountered greater resistance and difficulties in conducting field research in the Pearl River Delta region. The local terrain is mainly hilly, and there are many dialects and scattered populations. It is difficult to communicate with the farmers during the investigation and interview period, and the research efficiency is low.

A sample survey was conducted among white shrimp farmers, which was conducted in the form of face-to-face communication with the farmers, and the obtained information was filled in the questionnaire. The effective sample size obtained from the survey was 297 households, including 146 households in Hebei Province, 151 households in Shandong Province, 197 households in soil pond farming, and 100 households in factory farming. Shrimp farming in soil ponds has a long history in China, while factory farming technology is a modern breeding technology. This article uses the super-efficiency SBM-DEA non-expected output model, taking the carbon emissions during the breeding cycle as the non-expected output and combining input and output evaluation to assess the comprehensive efficiency of shrimp farming. The indicators are shrimp seedlings, feed, shrimp medicine, water and electricity expenses, land rent, fixed asset depreciation, and labor costs (self-owned labor is calculated based on the average wage of local labor). The output indicators are production, sales, and carbon emissions.

AGE DISTRIBUTION

As the implementers of agricultural production activities, the age of farmers significantly impacts production activities and decision-making implementation. The age distribution of surveyed sample farmers is shown in **Table 1**. Most of the sample farmers are aged 51-55 years old, with 77 people, accounting for 25.93% of the total sample, followed by 46-50 years old group with 65 people, accounting for 21.89% of the total sample; 41-45 years old farmers with 53 people, accounting for 17.85% of the surveyed farmers; 56-60 years old with 48 people, accounting for 16.16% of the valid questionnaires; and farmers under 41 years old with 37 people, and those over 60 years old with 17 people, accounting for 12.46% and 5.7% of the total sample respectively. From the age distribution, it can be seen that the main labor force in the shrimp farming industry in the surveyed area is middle-aged and elderly farmers aged 45-55 years old, accounting for nearly half of the total sample, which is consistent with the distribution of rural labor force in China. This is in line with the distribution of the rural labor force in China, indicating that the aquaculture industry in China faces serious problems with the aging labor force and the loss of the young labor force.

Table 1. Distribution of sample age groups

Age Group	Sample size	Proportion situation
Under 41 years old	37	12.46%
41-45 years old	53	17.85%
46-50 years old	65	21.89%
51-55 years old	77	25.93%
56-60 years old	48	16.16%
Over 60 years old	17	5.7%
Total	297	100%

Table 2. Carbon Emission Factors[a]

Energy and materials	Carbon emission coefficient (kg CO2/kg)
feed	0.41
diesel oil	3.17
consume power	0.997
Organic pollutants	3.08

[a]The data is sourced from the IPCC emission factor database

RESEARCH METHOD

CARBON EMISSION ESTIMATION

The carbon footprint of the shrimp aquaculture cycle is the total carbon emissions during the cultivation cycle of shrimp from seedlings to adults, including feed production, feed transportation, electricity for water pumps and aerators, and organic pollutant emissions. Factors such as shrimp seedling transportation can be ignored due to their small volume and inconsistent transportation distances. Since adult shrimp are purchased by buyers who come to the farm, transportation emissions can also be excluded from the cultivation cycle. Therefore, carbon emissions are divided into carbon emissions from feed transportation diesel, carbon emissions from feed production, carbon emissions from electricity, and carbon emissions from organic pollutants in shrimp. This article assumes[20] that a small truck with a capacity of 2 tons is used for feed transportation, traveling a distance of 100km. The fuel consumption of the truck per 100km when fully loaded is 15L, with a diesel density of 0.85kg/L, so the fuel consumption for one trip is 15L × 0.85kg/L = 12.75kg. The number of truck trips is determined by dividing the feed quantity by the truck capacity and rounding to the nearest whole number. The carbon emission coefficients for feed, diesel, electricity, and organic pollutants are shown in **Table 2**, with some coefficients sourced from the IPCC emission factor database. The evaluation results are shown in **Figure 2**. It can be seen from the figure that the carbon emission level of industrial aquaculture technology is much higher than that of pond aquaculture technology. Still, it has shown a decreasing trend in the past two years, with the potential to reduce aquaculture carbon emissions further in the future. The carbon emission level of pond technology is lower and has also shown a decreasing trend in the past two years.

DEA MALQUIST INDEX MODEL

This article calculates the production efficiency of the South American white shrimp aquaculture industry using total factor productivity as the measurement standard, based on the Malmquist index model, to assess and compare the production levels of two aquaculture models. The Malmquist index was first proposed by Sten Malmquist in 1953, and in 1982, Caves and others used it from a multi-input-output perspective to represent changes in total factor productivity (TFP). Subsequently, Caves[21] and Fare[22] further decomposed total factor productivity into the comprehensive technical efficiency change index (EFFCH) reflecting differences in technical capabilities and the technical progress index (TECH) reflecting changes in the production function, where the former is the ability to achieve maximum output under given input conditions. The latter is the rise of the production frontier caused by scientific and technological progress. The comprehensive technical efficiency can be further decomposed into scale efficiency change (SECH) and pure technical efficiency change (PECH). The Malmquist index has wide applications in the field of economic analysis. Based on the definition of total factor productivity by scholars such as Caves, the formula for the Malmquist index can be expressed as:

$$M^{t}(y^{t+1},x^{t+1},y^{t},x^{t})=\frac{D^{t}(y^{t},x^{t})}{D^{t+1}(y^{t+1},x^{t+1})} \tag{1}$$

$$M^{t+1}(y^{t+1},x^{t+1},y^{t},x^{t})=\frac{D^{t+1}(y^{t},x^{t})}{D^{t+1}(y^{t+1},x^{t+1})} \tag{2}$$

In the equations (X^{t+1}, Y^{t+1}) and (X^{t}, Y^{t}), X^{t+1} and Y^{t+1} represent the input-output vectors in periods t+1 and t, respectively; $D_0{}^{t}$ and $D_0{}^{t+1}$ represent the technological efficiency levels in periods t and t+1 with the reference set being the technology Tt in period t. Taking into account the differences caused by the arbitrariness of period selection, Caves and Far calculate the geometric mean of equations (1) and (2), further transforming the Malmquist index formula into:

$$\begin{aligned}M^{t+1}(y^{t+1},x^{t+1},y^{t},x^{t})&=\frac{D^{t}(y^{t},x^{t})}{D^{t+1}(y^{t+1},x^{t+1})}\\&\times[\frac{D^{t}(y^{t},x^{t})}{D^{t+1}(y^{t+1},x^{t+1})}\ \frac{D^{t+1}(y^{t+1},x^{t+1})}{D^{t}(y^{t+1},x^{t+1})}]^{1/2}\\&=\mathrm{EFFCH}^{t}\times\mathrm{TECH}^{t}\end{aligned}$$

When EFFCH>1, it indicates an improvement in overall technical efficiency. Otherwise, it indicates a decline; when TECH>1, it indicates technological progress; otherwise, it indicates a decrease in technological level. Since overall technical efficiency can be further decomposed into pure technical and scale technical efficiency, the formula for total factor productivity can be further expressed as MI=EFFCH×TECH=PECH×SECH×TECH.

Compared to the traditional DEA model, the SBM super-efficiency model introduces slack variables to avoid biases caused by radial and angular measurements, making the analysis results more accurate. At the same time, the efficiency value of the traditional DEA model is maximized at 1, making it difficult to directly compare research objects

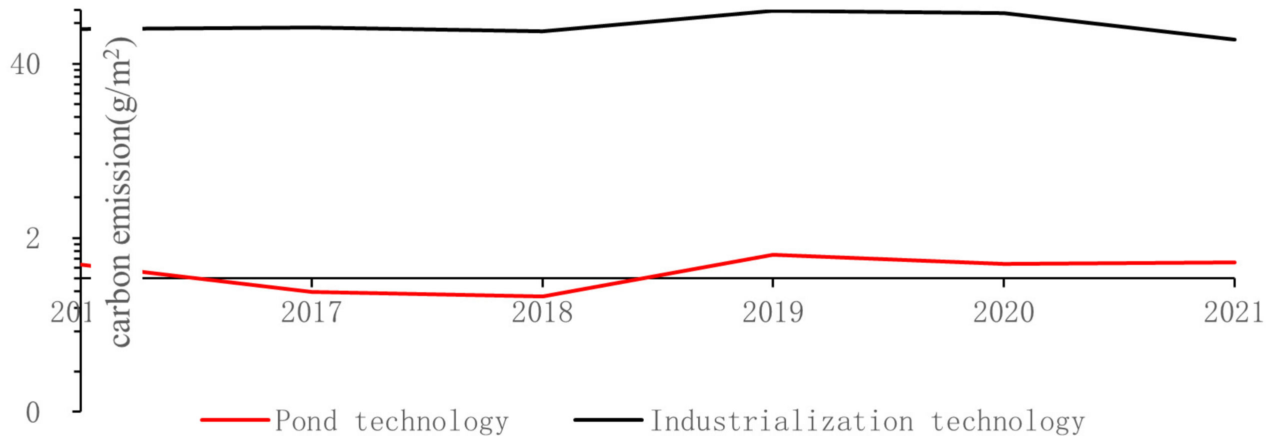

Figure 2. Estimation of carbon emissions during the aquaculture cycle

that have all reached the maximum efficiency value. However, the optimal efficiency value of the super-efficiency model exceeds 1, allowing for better comparisons between different objects.

CASE ANALYSIS

Case analysis is a method of gaining overall understanding through detailed and careful analysis of representative research objects. This article conducts a detailed recording and analysis of the scale, farming conditions, benefits, and cognitive demand of typical pond-based and factory-based technical farmers to identify the current problems in the shrimp farming industry and the path and influencing factors of technology diffusion.

RESULTS

COMPREHENSIVE EFFICIENCY CALCULATION

The comprehensive production efficiency calculation results of the industrialized and pond aquaculture technology models are shown in **Figure 3**. The figure shows that both technology models are efficient, and industrialized aquaculture technology has reached the optimal production frontier. Considering environmental protection, production capacity, and profit, the comprehensive production efficiency of industrialized aquaculture technology is slightly higher than pond aquaculture technology's, with a mean difference in production efficiency of 0.179. At the same time, in 2017, the comprehensive efficiency of both models reached the lowest in five years, indicating that the aquaculture situation in the surveyed area was generally poor that year, mainly due to frequent shrimp diseases and very low shrimp survival rates, which greatly impacted the production capacity and profits of aquaculture farmers. In 2021, the comprehensive efficiency of both models reached the highest in five years, indicating a good shrimp aquaculture situation in the region that year, mainly because the epidemic showed a trend of slowing down and ending in 2021.[23] There were positive expectations and attitudes towards the shrimp aquaculture industry and consumer market, ending the behavior of reducing aquaculture inputs and scale during the epidemic. Overall, in recent years, the comprehensive efficiency of both technology models has shown a fluctuating upward trend, but the fluctuation of industrialized aquaculture technology is greater. Therefore, considering carbon emissions, industrialized aquaculture technology is still a better choice than pond aquaculture, as it has higher income and land utilization rates. Additionally, industrialized technology is less affected by external factors such as climate, thus having stronger adaptability.

THE IMPACT OF INPUT FACTORS ON OUTPUT

From the previous section, it can be seen that the comprehensive efficiency of the factory model is superior to that of the pond model. To further determine the impact of various input factors on production capacity, this study uses Stata software. It employs a Level model to calculate the impact coefficients of input factors independently. Here, we refer to production as Y, shrimp fry cost as S_1, bait cost as B, shrimp medicine fee as S_2, water, electricity, and coal cost as W, depreciation cost as D, land rent as L_1, and labor cost as L_2. We assume the model to be $Y=\beta_0+\beta_1S_1+\beta_2B+\beta_3S_2+\beta_4W+\beta_5D+\beta_6L_1+\beta_7L_2+\mu$.

The regression results are shown in the **Figure 4**:

$Y=0.86S1+0.017B+0.002S2+0.2W+0.1D+0.14L1+0.05L2+0.78.$

From the regression results, it can be seen that the impact of shrimp seedlings' input on production capacity is the greatest. The larger the shrimp seedlings, the higher the stocking density, which results in higher unit output under the condition of constant survival rate. This is also an important explanation for the higher comprehensive efficiency of the industrialized model. Secondly, water, electricity, and coal costs are significant. Due to reasons such as winter heating and groundwater extraction, the water, electricity, and coal costs in industrialized aquaculture are

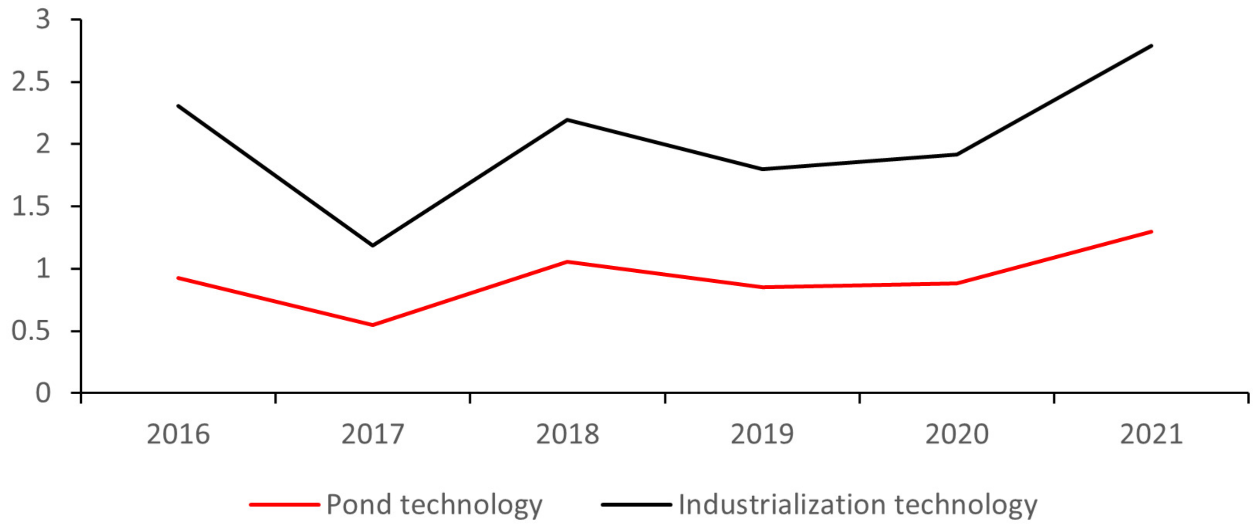

Figure 3. Calculation Results of Comprehensive Efficiency of Pond and Industrialization Technology

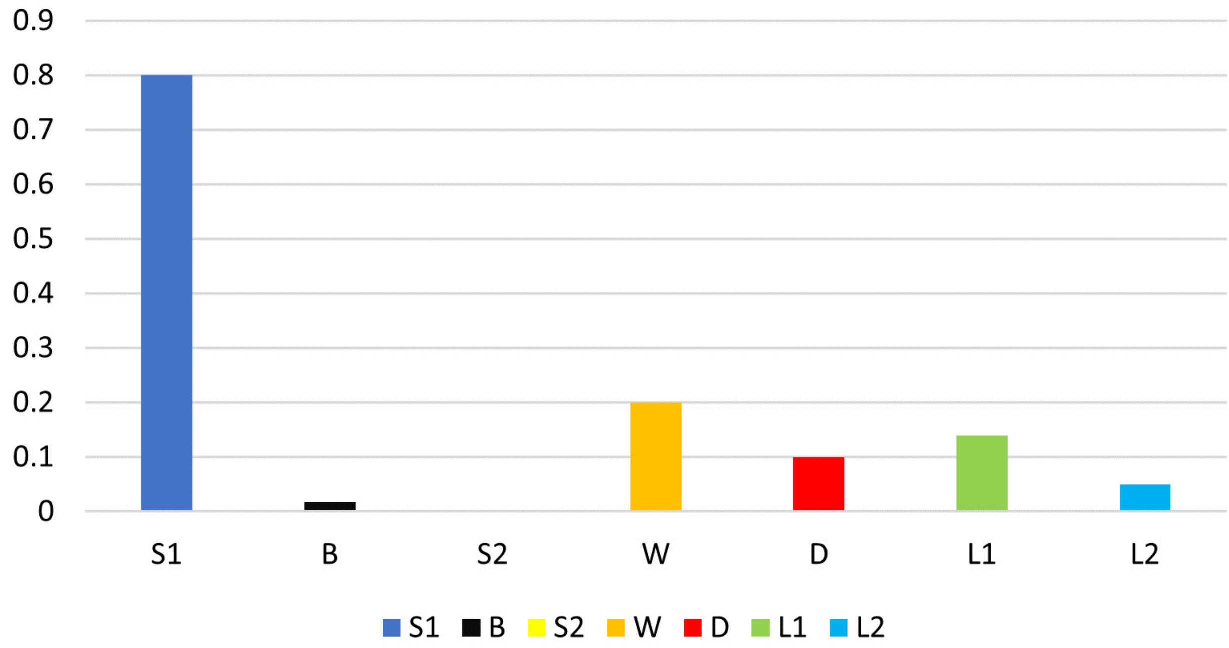

Figure 4. The coefficient of influence of each input factor

much higher than those in pond aquaculture, which once again proves the superiority of industrialized production capacity. The smallest impact factor is shrimp medicine costs. Research shows that the current application of shrimp medicine in the surveyed areas is still in a "blind stage." Aquaculture farmers rely more on experience and word of mouth for medication, leading to common cases of misuse and overuse of medication in the aquaculture industry. Improper use of shrimp medicine results in difficulty in demonstrating efficacy and may even have negative impacts.

The above results clearly show that Industrialization farming technology is superior to pond farming in terms of comprehensive efficiency. However, the team found that factory farming technology did not spread quickly during the research process. Therefore, this article will study the sources of factory farming technology and provide a case study to analyze the influencing factors of technology diffusion.

THE SPREAD OF FACTORY FARMING TECHNOLOGY

ORIGIN OF TECHNOLOGY ADOPTION

Industrialized aquaculture technology evolved from the initial fish pond aquaculture. In the 1980s, with the emergence of artificial breeding and artificial feed, it gradually became popular and rapidly expanded in the following decades. According to local research station staff in Hebei Province, industrialized aquaculture in the area originated from factory breeding in the 1970s and 1980s. During the idle period of breeding, people found that shrimp aquaculture had better results than pond aquaculture, leading to the gradual development and spread of shrimp factory aquaculture. Although factory aquaculture has shown good results and substantial yields, becoming an industry consensus, the diffusion of factory technology is not ideal. Most farmers still use traditional pond aquaculture methods. Pond aquaculture requires a large land area but has low stocking density, making it difficult to meet the large domestic demand for shrimp. This has led to heavy reliance on imported shrimp in the market. Additionally, pond aquaculture mostly relies on groundwater sources and lacks water treatment processes, leading to issues such as shrimp production decline and environmental pollution due to excessive groundwater use. Factory aquaculture, on the other hand, occupies a relatively small land area with high stocking density and substantial yields. Promoting the diffusion of factory aquaculture technology can significantly fill the supply gap in the domestic shrimp market. Factory aquaculture includes water treatment processes, is less affected by environmental factors, and causes less environmental pollution. In theory, the shrimp aquaculture industry needs to promote factory aquaculture technology. However, in reality, the diffusion of factory technology is slow. Research has also shown that the proportion of factory aquaculture among farmers is low. What is the reason for this?

CASE ANALYSIS

CASE1:

Wang, a 56-year-old male farmer, resides in Dongxin Farm, Lianyun District, Lianyungang City, Jiangsu Province. He and his wife jointly operate a 113-acre aquaculture pond. Their daughter is married and working, while their son is still studying. Wang adopts a mixed farming model of fish and shrimp, with a large proportion of grass carp, crucian carp, and silver carp and a smaller proportion of South American white shrimp. In 2023, the shrimp production was 30,000 catties, generating an income of 450,000 yuan, while the fish farming income was 1 million yuan. Wang mentioned that after deducting costs, they still lost 40,000 yuan mainly due to the continuously low fish prices, unstable shrimp production, and rising costs of feed and pond bottom rent. When asked about considering a factory farming model, Wang said there were no such operations nearby, but he heard about some small greenhouse farming in Shandong Rizhao. He also mentioned the lack of information and promotion about factory farming models. Regarding government policies, Wang stated that the local government's role in aquaculture is limited, with minimal technical guidance and promotional assistance. Pond bottom rents have increased during good market conditions and have not decreased in recent years despite poor market conditions. Wang also heard that due to issues like non-compliant wastewater discharge, the government plans to ban local individual farmers and hand over aquaculture to state-owned enterprises, leaving local farmers uncertain about their livelihoods. As for fisheries insurance, Wang mentioned hearing about it during meetings and expressed interest in learning more and joining, but has not found a way to get in touch.

In this case, the fish farmer is a typical example of scale-based pond aquaculture, with relatively low unit input but high overall investment. This makes it prone to losses during low prices or unstable production periods. At the same time, regarding technological diffusion, this farmer has limited access to information on industrialized aquaculture and has not received heterogeneous or homogeneous dissemination. They also receive little support and guidance from the local government during farming, with a lack of government promotion. Regarding fisheries insurance, due to the instability of survival rates and production, this farmer and their peers in the vicinity have a strong desire to engage with and join but lack an understanding of insurance mechanisms and have limited access to specific information and policies, leaving them to face aquaculture risks alone.

CASE2:

Zhuang, a male farmer 45 years old with a college degree, lives in Xiaohai Village, Taolu Town, Donggang District, Rizhao City, Shandong Province. He runs a 2000-square-meter factory for intensive farming of South American white shrimp with his wife. They have two sons who are already working. Mr. Zhuang studied shrimp farming during college and started his own shrimp farming business after graduating in 1996. He temporarily stopped the business but resumed it in 2015. He uses a high-density farming method for South American white shrimp, with a density of up to 1000 shrimp per cubic meter and a survival rate of 60%. In 2023, his shrimp farming income reached 1 million yuan, with a net income of tens of thousands. When asked about the farming situation of his peers, Mr. Zhuang mentioned that many in the village are also engaged in factory farming, and some have learned from him. Local companies and the government sometimes organize seminars to exchange farming techniques and experiences. However, Mr. Zhuang is not entirely satisfied with the policies. He wants to expand his business, but due to issues like lack of groundwater, the government restricts the expansion and construction of shrimp farms, not allowing the construction of farming sheds. He is also interested in fishery insurance but lacks access to information and channels for dissemination.

This case is a relatively typical factory farming model. Although the farming area is only 2000 square meters, the investment per unit is high, the intensification level is high, and the farming density and survival rate are high. Therefore, the unit farming output is large and relatively stable, making it less likely to incur farming losses. Regarding technology dissemination, Mr. Zhuang, as a university student specializing in shrimp farming, is not only a recipient of technology diffusion but also a channel for research institutions to disseminate information to ordinary farmers. He also serves as a source of homogenized information for spreading technology to surrounding farmers. The heterogeneous channels through which governments and enterprises disseminate technology diffusion to farmers also play an important role in this case. With the combined effects of homogenized and heterogeneous dissemination, this region's factory farming technology diffusion level is relatively ideal.

Therefore, this article combines existing literature, theory, and case analysis to summarize and analyze the path of agricultural technology diffusion and its influencing factors.

DISCUSSION AND CONCLUSION

ANALYSIS OF THE DIFFUSION PATH OF AGRICULTURAL TECHNOLOGY

Social network communication plays a very important role in diffusion of agricultural technology. Agricultural technology diffusion among farmers is not a linear and regular process but a social and "epidemic-like" diffusion. Social network communication has always been the main channel for the diffusion of shrimp farming technology. Farmers obtain farming technology information through communication and learning with relatives, neighbors, and colleagues and will imitate and learn from farmers who achieve higher profits.[24] Regarding the technology acquisition level, social network communication includes heterogeneous and homogeneous diffusion.[25] The technology diffusion pathways are shown in **Figure 5**.

HETEROGENEOUS TRANSMISSION

Heterogeneous diffusion refers to the spread of agricultural technology among different social strata, where social strata can refer to various endowments. Heterogeneous diffusion is generally more difficult because the spread of technology and adopters are at different levels. Therefore, significant differences in forms, values, and development expectations make communication between the two parties more challenging. However, once heterogeneous diffusion occurs, agricultural technology has broken through the barriers between social strata and organizations, achieving diffusion across levels, which is very important and effective in technological innovation. From the perspective of vertical heterogeneous diffusion, technological innovation spreads from research institutes, universities, and laboratories to governments and enterprises through heterogeneous diffusion and is then adopted. The government promotes and disseminates the innovation or enterprises and provides guidance and support to spread it to large agricultural households or ordinary farmers. At the same time, large agricultural households will also spread technological innovation to ordinary farmers and have it adopted by their driving force.

HOMOGENOUS TRANSMISSION

Homogeneous diffusion refers to disseminating agricultural technology among groups of people with similar social status and relatively similar endowments. Homogeneous diffusion is generally easier and more frequent because farmers within the same social class and organization share similar cognitive values, leading to better communication and trust than heterogeneous diffusion. However, due to the similarity in cognitive processes within the organization, the value of homogeneous diffusion is much lower than that of heterogeneous diffusion. Excessive closed and rigid homogeneous diffusion may even hinder heterogeneous diffusion, which is not conducive to spreading technological innovation. From the perspective of horizontal homogeneous diffusion, technological innovation is disseminated and adopted through online and offline communication among enterprises, large-scale agricultural households, and ordinary farmers. Both homogeneous and heterogeneous diffusion channels constitute the diffusion of agricultural technology, thereby achieving the true success of a technological innovation.

FACTORS INFLUENCING SHRIMP FARMING TECHNOLOGY DIFFUSION

The diffusion pathways of shrimp aquaculture technology are shown in **Figure 6**. Shrimp aquaculture technology spreads through social networks and is influenced by external and internal environments. The external environment includes the policy environment, economic market environment, and geographical environment, while the internal environment includes technological attributes and the conditions of farmers themselves. Heterogeneous diffusion refers to the dissemination between different levels of technology research units, government, enterprises, and farmers, which involves technology extension and enterprise assistance. Homogeneous diffusion refers to the dissemination among farmers at the same level, involving the exchange of experiences and confidence. It has been the main channel for the diffusion of agricultural technology in the past. In the following text, we will analyze the internal and external influencing factors of the diffusion of factory-scale shrimp aquaculture technology from the perspectives of homogeneous and heterogeneous diffusion in social networks.

INTERNAL ENVIRONMENTAL FACTORS

1. Factory technology attributes: high capital and technical requirements
   The factory farming technology is fundamentally different from traditional planting and pond farming in that it requires the construction of farming facilities, the purchase of equipment for water treatment, aer-

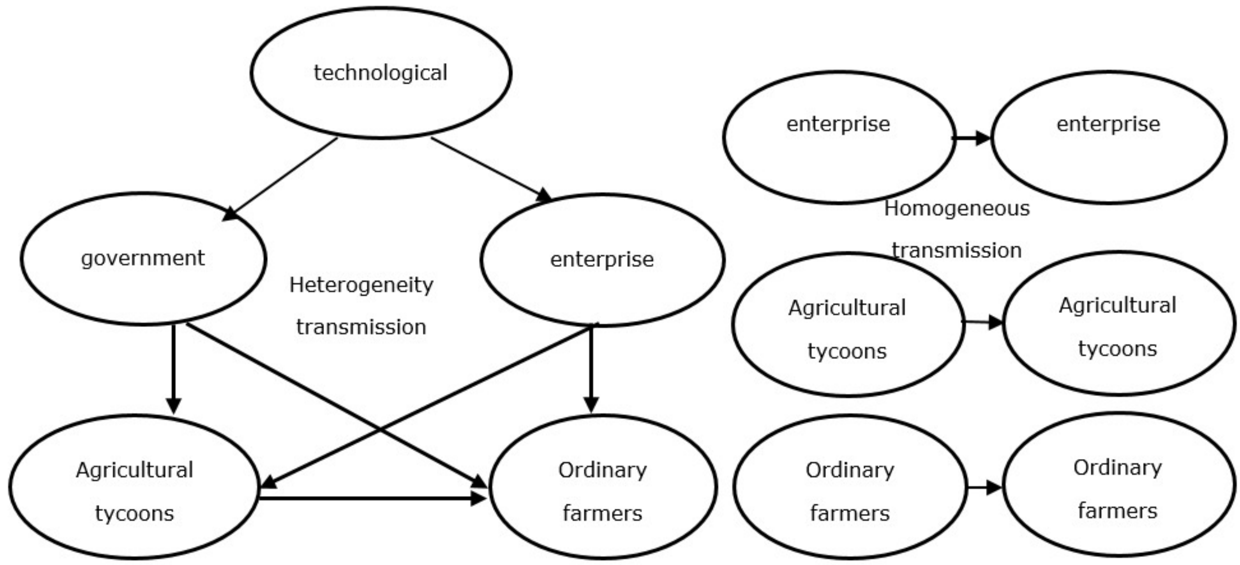

Figure 5. Heterogeneous and Homogeneous Transmission Paths

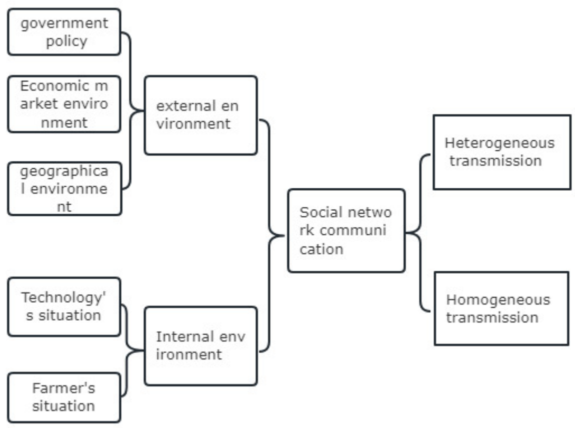

Figure 6. Factors affecting the diffusion of shrimp farming technology

ation, etc., as well as the input of a large number of shrimp seedlings, feed, and reagents for high-density intensive farming. Therefore, factory farming technology has a higher requirement for capital investment, with a long investment return period, and profits may only be obtained after several years. At the same time, factory farming requires real-time monitoring and adjustment of water quality, microorganisms, oxygen content, and phosphorus and ammonia nitrogen levels through instruments and reagents, which demands a higher level of technical expertise from farmers. Factory technology's high investment and technical nature determine that its diffusion rate will be faster among enterprises and large-scale farmers but slower among ordinary farmers. As a result, the diffusion speed of technology from enterprises and large-scale farmers to ordinary farmers is slowed down. To some extent, the inherent characteristics of factory technology hinder its heterogeneous dissemination and diffusion speed.

2. Small-scale farmers have the following characteristics: weak capital accumulation, low investment desire, and a strong risk-averse mentality.

Most of the livestock breeders are farmers who have transitioned or are part-time farmers, still belonging to the category of small-scale farmers. The inherent characteristics of small-scale farmers for thousands of years have determined that the capital accumulation and technical support of livestock breeders are much weaker compared to large-scale farmers and enterprises, and their compatibility with the high requirements of factory farming technology is low. At the same time, small-scale farmers have a strong risk-averse awareness with weak investment desires. Most livestock breeders would rather earn less or even incur small losses each year than take risks for large capital investments. In the absence of loan subsidies and support policies, most livestock breeders also find it difficult to meet the financial and technical access thresholds of factory farming technology. Even if they receive information on heterogeneous dissemination from upper-level enterprises and homogenized dissemination from peers, and are interested in adopting new technologies, they are unable to implement them due to their own conditions. The stark contrast between the high technological threshold and the weak capital and technical accumulation of livestock breeders severely hinders the diffusion of factory farming technology and the process of livestock breeders adopting new technologies.

Through case studies and research, it has been found that the lack of fishery insurance mechanisms is a common problem in the shrimp farming sector, increasing the risk of investment for farmers and hindering their willingness to adopt new technologies.

Some farmers intend to try new farming technologies but are reluctant to do so due to the high risks involved. A sound fishing insurance mechanism can reduce the investment losses from farming failures for farmers, enabling them to invest and try new technologies with confidence and greatly promoting the diffusion of industrialized technologies. At the same time, during the investigation, the team found that there were very few agricultural cooperatives in the shrimp farming villages, and some agricultural cooperatives in certain villages were in name only. The government should actively organize and promote agricultural cooperatives. The scale and capital requirements of industrialized technology are significant. By pooling funds, villagers can establish agricultural cooperatives that integrate breeding, processing, and cold-chain transportation. This not only reduces costs and expands the breeding scale but also extends the industry chain, increases the added value of shrimp farming, and improves breeding income. At the same time, shrimp farmers are in a weak position in shrimp trading. Agricultural cooperatives can help bridge the gap in trading positions and improve the status of shrimp farmers. The establishment of agricultural cooperatives can not only attract nearby farmers to join but also stimulate the spread of industrialized technology to the surrounding areas.

3. The universality of technology determines the level of diffusion.
   The universality of a technology largely determines whether it can spread in a region or even nationwide. The higher the universality, the faster and wider the technology will spread. The characteristic of factory farming technology is indoor farming with mechanized equipment, requiring lower climate and water quality conditions and having stronger environmental adaptability compared to the traditional pond and other farming techniques. Traditional ponds can only produce two crops a year, while factory farming can produce 3-4 crops, gaining a competitive advantage in off-season pricing. This leads to increased production and income. Therefore, factory farming technology has a wide diffusion range, with farmers across the country adopting factory farming techniques.
   However, in other aspects, there is a significant difference in the universality of factory technology compared to pond technology. As the name suggests, adopting factory technology is like setting up a small factory, requiring a large amount of initial capital and risk tolerance, as well as specialized knowledge and skills. These requirements are not suitable for small farming communities compared to pond technology, thus hindering, to a certain extent, the speed and scope of technology diffusion. However, with the continuous improvement of the professional level, knowledge base, and capital accumulation of small farming communities in recent years, these obstacles are gradually decreasing. In addition, local policies vary by region. Ponds are generally located at pollution-free river mouths or seashores, directly utilizing ditches and tides for water intake and exchange. Policies mainly involve land use and water source pollution. Factory farming mostly relies on groundwater and requires boiler heating in winter, so related policies also involve business licenses, groundwater regulations, and bans on burning boilers. For example, the Department of Agriculture in Shandong Province strongly supports factory farming, and local policies provide assistance and support for technology upgrades, such as subsidies for boiler-to-electricity conversion. Hebei Province has stricter approval for factory farming, and the implementation of supportive policies is not sufficient, resulting in a slower diffusion of factory technology in Hebei Province compared to Shandong Province. The aforementioned policies mainly hinder small farmers, while large farms and agricultural companies are less affected due to their professionalism. The low universality of factory technology in relation to local policies mainly hinders the heterogeneous transmission of technology from farms and companies to small farmers.

EXTERNAL ENVIRONMENTAL FACTORS

1. Policy instability and deficiencies
   Compared to other agricultural industries, the shrimp farming industry has higher requirements for the policy environment and is more sensitive to policy responses. Industrialized technology farming requires the construction of farming workshops and warehouses, leading to high fixed costs. Therefore, there is a high demand for land lease terms, as short-term leases can result in excessively high fixed costs, damaging shrimp farming profits and even causing losses. Therefore, the diffusion of industrialized technology requires relatively stable and long-term land lease policies so farmers can invest and introduce new technologies with peace of mind. Currently, land policies with one or a few years of lease terms seriously hinder the diffusion of industrialized technology. Additionally, most industrialized farms have not adopted recirculating aquaculture systems, leading to a heavy reliance on groundwater. Restrictions on groundwater increase water source costs and acquisition difficulties, to some extent, impeding the spread of industrialized technology in homogeneous dissemination.
   In terms of heterogeneous diffusion of technology, the government, research stations, and enterprises' policies of taking technology to rural areas will have a positive impact on the diffusion of factory technology. However, it was found during the investigation that most livestock breeders did not receive government publicity and technical guidance. The relevant training and guidance from research stations mainly focused on large-scale breeders and enterprises, providing little help to ordinary breeders. Unlike the planting industry, enterprises are in a semi-absent

state in the heterogeneous diffusion of shrimp farming technology: the planting industry has developed a very standardized market for seedlings and fertilizers after a long period of development, but the market for shrimp seedlings and feed is extremely chaotic. The phenomenon of purchasing and using poor-quality seedlings and animal feed is very common, leading to frequent communication among breeders but little connection with enterprises. Therefore, the heterogeneous diffusion of factory technology from enterprises to breeders is insufficient. Projects led by the government with the participation of enterprises and breeders are very few, and there are few business connections between enterprises and breeders. The diffusion pathway of shrimp farming technology between enterprises and breeders is severely damaged. For example, in the issue of agricultural cooperatives mentioned earlier, the government should act as a mediator to actively guide cooperation between enterprises and farmers, promote enterprises joining agricultural cooperatives, or have enterprises lead farmers. Enterprises, as the target of technology diffusion, have a much higher level of awareness and mastery of new technologies compared to farmers. Encouraging enterprises to lead farmers can not only bring funds and technology to farming households but also introduce strict management standards and innovative business concepts, promoting the diffusion and learning of new technologies. The rural land system in China is collectively owned, and shrimp farming is done through land contracting. Extending the land lease term can encourage livestock farmers to invest in building breeding ponds and purchasing fixed equipment, adopting advanced new technologies, and promoting the diffusion of industrialization technology. Industrialization requires a large amount of water supply. Due to current restrictions on the use of groundwater along the coast, the introduction cost of industrialization technology has increased. The government providing water subsidies can reduce the cost of technology adoption and promote the diffusion of industrialization technology.

2. The economic environment influences the internal environment, while the market environment drives technological diffusion.
   The economic and market environment will greatly influence the diffusion speed of shrimp farming technology. Only when the economy and market are good will farmers consider investing more funds and energy into new technologies. Factory farming is a technology that requires high investment, and a good internal environment requires a good economic environment. In a good economic environment, farmers are more willing to learn advanced technologies from enterprises and peers, which can promote the diffusion of homogeneous and heterogeneous factory farming technologies. There are significant differences between the shrimp market and traditional farming markets: ordinary farming prices fluctuate less, and supply and demand relationships are constantly changing. However, the domestic shrimp market is large, and shrimp prices have remained high due to supply-demand imbalances. Therefore, farmers can easily achieve profitability while ensuring production. Farmers continuously learn and innovate in farming technology to pursue higher yields, which greatly promotes the diffusion and adoption of factory farming technologies by farmers.

POLICY SUGGESTION

1. Reduce loan review standards and interest rates and provide technical support.
   Due to the high cost of adopting industrialization technology and the large capital requirements of livestock farmers, lowering the loan approval standards and interest rates by the government can make it easier for livestock farmers to reach the technology access threshold, thereby accelerating the diffusion speed of industrialization technology. At the same time, the previous text mentioned that factory farming technology requires farmers to be proficient in applying and analyzing relevant equipment and microdata, which can be difficult. This difficulty may pose certain obstacles to the diffusion of technology. To address this, the government and technical personnel from research stations should establish close connections with farmers, providing technical consultation and on-site assistance both online and offline. This helps farmers overcome the challenges of applying technology. Additionally, proficient farmers in technology application can further diffuse the technology through cooperatives or homogenous dissemination, which plays a positive role in promoting the diffusion and adoption of factory farming technology.
2. Promote agricultural cooperatives and strengthen cooperation between farmers and agricultural enterprises
   Agricultural cooperatives play a significant positive role in promoting the dissemination of heterogeneous and homogeneous agricultural technologies. On one hand, through close communication and collaboration, advanced technologies and knowledge can be spread and diffused, allowing marginal farmers to acquire advanced technologies and information from core peers, as well as receive technical and financial assistance from leading enterprises, thus accelerating industrial transformation and upgrading. On the other hand, farmers can form industrial clusters and joint-stock enterprises through agricultural cooperatives, addressing real issues such as insufficient funds, lack of information, and backward technical management among small-scale farmers, pooling resources such as manpower, land, and funds from villagers to collectively drive the transformation and upgrading of the local shrimp farming industry. The government should also actively organize and promote cooperation between local enterprises and

villagers, including but not limited to symposiums, enterprise visits, enterprise sponsorships, and individual-enterprise collaborations, breaking down organizational barriers and promoting the diffusion and upgrading of technological information across industries.

3. Strengthen industry norms and promote green aquaculture.

   The text mentions that industrialization is restricted in some areas due to reasons such as coal burning polluting the air, untreated wastewater polluting the environment, and overuse of groundwater, hindering the diffusion of technology. Therefore, the government should specify industry standards, such as completely banning coal-fired boilers and improving subsidy policies, establishing sound regulations for wastewater treatment and water recycling systems, and reducing harm and impact on local environment and water sources, thereby reducing restrictions on industrialization technology by local policies, and promoting the diffusion of technology in local industries.

ACKNOWLEDGMENTS

The Ministry of Agriculture of the People's Republic of China supported and financed this study through the China Agriculture Research System (Grant No. CARS-48).

AUTHORS' CONTRIBUTION

Methodology: Hongtao Jin (Equal), Lele Xiang (Equal), Fang Chen (Equal). Writing – original draft: Hongtao Jin (Equal), Fang Chen (Equal), Wenjun Zhu (Equal). Data curation: Hongtao Jin (Equal), Fang Chen (Equal), Wenjun Zhu (Equal). Software: Hongtao Jin (Equal), Lele Xiang (Equal), Fang Chen (Equal). Conceptualization: Hongtao Jin (Equal), Fang Chen (Equal), Wenjun Zhu (Equal). Writing – review & editing: Hongtao Jin (Equal), Fang Chen (Equal). Supervision: Hongtao Jin (Equal), Fang Chen (Equal). Funding acquisition: Hongtao Jin (Lead).

Submitted: April 15, 2024 CDT, Accepted: May 03, 2024 CDT

REFERENCES

1. Xin LJ. Dietary structure upgrade of China's residents, international trade and food security. *Journal of Natural Resources*. 2021;6:1469-1480. doi:10.31497/zrzyxb.20210609

2. Liu ZF. Research on the Status, Causes and Governance of Marine Fishing Ground Desertification. *Issues in Agricultural Economy*. 2019;6:105-116. doi:10.13246/j.cnki.iae.2019.06.009

3. Guo YJ. Reconstruction of agricultural technology diffusion system under Internet thinking. *Agricultural Economy*. 2017;3:12-14. doi:10.3969/j.issn.1001-6139.2017.03.004

4. Li Q, Yang WJ, Li K. Role of Social Learning in the Diffusion of Environmentally-friendly Agricultural Technology in China. *Sustainability*. 2018;10(5):1527. doi:10.3390/su10051527

5. Yang G, Qian NW, Chen C, et al. Promotion methods, social learning and environmentally friendly agricultural technology diffusion: A dynamic perspective. *Ecological Indicators*. 2023;154:110724. doi:10.1016/j.ecolind.2023.110724

6. Asmaa ZYA, Ahmed HL. Suggestion Patron to Diffusion Evaluation the Fodder Agricultural Technologies in Ninevah Province. *IOP Conference Series: Earth and Environmental Science*. 2023;1256:012136. doi:10.1088/1755-1315/1259/1/012136

7. Gong BL. Technology Diffusion and Regional Productivity Gaps in China's Agricultural Sector. *Economic Research Journal*. 2022;11:102-120.

8. Wang LY. *Research on Simulation Model of Agricultural Water-Saving Technology Diffusion Based on Agent*. Master's thesis. Xi'an University of Technology; 2022. doi:10.27398/d.cnki.gxalu.2022.000920

9. Gabriel SS, Edward DP. Peer effects in the diffusion of water-saving agricultural technologies. *Agricultural Economics*. 2019;50(6):693-706. doi:10.1111/agec.12518

10. Yu Y, Li JW. Simulation research on agricultural innovation technology diffusion based on ABM modeling. *Science and Technology Management Research*. 2023;43(11):191-199. doi:10.3969/j.issn.1000-7695.2023.11.024

11. Li HF, Wei SQ, Wei SB. Analysis on the influencing factors of the diffusion of Chinese Taiwan's agricultural technology in China's Mainland from the perspective of farmers:Taking orchid planting industry in Guangdong-Taiwan agricultural cooperative experimental zone in Shaoguan of Guangdong province as an example. *Journal of Natural Resources*. 2020;7:1686-1698.

12. Xie PH, Wang SQ, Li LY. Research on Influencing Factors and Countermeasures of Internet of Things Technology Diffusion Behavior of Large Vegetable Growers. *Northern Horticulture*. 2023;23:135-143. doi:10.11937/bfyy.20231589

13. Li NN, Li TS, Yu ZS, et al. Factors influencing farmers' adoption of new technology based on Logistic-ISM model: a case study of potato planting technology in Dingxi City, Gansu Province. *Progress in Geography*. 2014;4:542-551.

14. Kuang HY. Study on the relation of rural social network and agricultural technology diffusion——taking the technology diffusion of pig raising on the country G as an example. *Studies in Science of Science*. 2014;10:1518-1524. doi:10.3969/j.issn.1003-2053.2014.10.010

15. Li HF, Wei SQ, Chen SL, et al. Characteristics of social network of Taiwan's orchid technology diffusion in Guangdong-Taiwan agricultural cooperative pilot zone in Shaoguan city,Guangdong province. *Geographical Research*. 2020;11:2479-2492. doi:10.11821/dlyj020190883

16. Li HF, Wei SQ. Developing Process of Questionnaire Statistics Dataset from Guangdong-Taiwan Agricultural Cooperative Experimental Area in Shaoguan of China. *Journal of Global Change Data & Discovery*. 2021;1:89-98. doi:10.3974/geodp.2021.01.12

17. Yari V, Margherita M, Teresa DG, et al. Technological innovation in fisheries and aquaculture: What are the "discourses" of the Italian policy network? *Marine Policy*. 2024;159:105947. doi:10.1016/j.marpol.2023.105947

18. Kodjo N, Chen S, Bin C. Aquaculture technology adoption and profitability of the polyculture system practiced by prawn and crab farmers: Case study of Anhui province in China. *Aquaculture Reports*. 2021;21:100896. doi:10.1016/j.aqrep.2021.100896

19. Obiero K, Waidbacher H, Nyawanda B, et al. Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquaculture International*. 2019;27(6):1689-1707. doi:10.1007/s10499-019-00423-0

20. Wu FF, Ji JY, Xv HD. Research on Carbon Footprint of Shrimp Pond Farming Based on LCA Method. In: *The 13th China Annual Conference of Management Science*. ; 2011.

21. Caves DW, Christensen LR, Diewert WE. The econmic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*. 1982;50(6):1393-1414. doi:10.2307/1913388

22. Fare R, Grosskopf S, Knox LCA. *Production Frontiers: Frontmatter*. Cambridge University Press; 1993. doi:10.1017/CBO9780511551710

23. Zhang WW. *Research on the Impact of COVID-19 on the Economic Benefits of Freshwater Aquaculture in China*. Master's Thesis. Shanghai Ocean University; 2022.

24. Yao H, Zhao CH, Gao QJ. The Organic Link between Farmers and Agricultural Technological Diffusion:the Evolution of Its Network Path. *Rural Economy*. 2021;12:117-125.

25. Du YP, Wang KW, Hu ZD. Agricultural Technology Diffusion and Path Anlysis from the Perspective of Social Capital. *Journal of Jianxi Agricultural University:Social Sciences Edition*. 2012;1:46-52. doi:10.3969/j.issn.1671-6523.2012.01.008