A Study on the Impact of Nuclear Pollution Discharge on the Seafood Industry in Coastal Cities Based on the DID-SARIMA Model

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Abstract. In recent years, the issue of nuclear wastewater treatment has garnered considerable attention. Investigating the specific impact mechanisms of nuclear pollution on the development of the seafood industry holds significant importance for national economic development. Based on this premise, this study first examines the influence of nuclear wastewater discharge from Country J on the willingness of City Q's residents to purchase seafood through a comparative survey. Then, a DID (Difference-in-Differences) model and a SARIMA (Seasonal Autoregressive Integrated Moving Average) time series model are constructed to analyze the impact mechanisms of nuclear pollution discharge on the seafood economy. The empirical results indicate that Country J's nuclear wastewater discharge practices negatively affect the cumulative growth rate of sales in City Q and also reduce residents' willingness to purchase seafood. Based on these findings, this study provides relevant policy recommendations for policymakers and stakeholders in the seafood industry to address potential environmental and economic challenges in the future.

Keywords: Nuclear Polluted Water Discharge, Seafood Industry Economy, DID, SARIMA Model.

1. Introduction

The issue of nuclear wastewater treatment at nuclear power plants in Country J has attracted considerable attention. Despite strong opposition from the domestic public and the international community, the government of Country J announced in late August 2023 that it would discharge nuclear wastewater stored in tanks at nuclear power plants into the ocean. "The planned release of contaminated water from storage tanks has raised concerns regarding its potential impact on marine life and human health through seafood consumption" (Bezhenar et al., 2021) [1]. The amount of nuclear wastewater within the plant area has exceeded 1.34 million cubic meters, with approximately 100 tons being added daily. According to relevant reports, the treated and diluted nuclear wastewater will be discharged into the sea via an approximately one-kilometer-long undersea tunnel, with the discharge plan extending over 30 years. Large gatherings have been held by citizens of both Country J and Country K to protest the government's forced implementation of the nuclear pollution discharge plan [2]. In China Fisheries Economics [3], Li Junqian (2012) indicated the influence of Japan's nuclear wastewater discharge on seafood markets in neighboring regions, attempting to analyze its intrinsic impact mechanisms and proposing major countermeasures and recommendations for China [4], which could serve as a reference for the domestic seafood market in dealing with uncertain events. In the field of economics, Lee (2020) employed the Difference-in-Differences (DID) method to study the impact of the construction and operation of the Mass Rapid Transit (MRT) system on neighborhood housing prices [5]. DID is a quasi-experimental design used to estimate the causal effect of interventions (Wing, 2024) [6], where in its basic form, the “control group” remains untreated at two time points, while the “treatment group” is fully treated at the second time point [7]. Caniglia (2020) mentions that this method relies on strong assumptions, requiring attention to ensure that these assumptions are met for causal interpretability of results [8].

The marginal contribution of this paper lies in exploring the potential impact of Country J’s nuclear wastewater discharge on the seafood industry in City Q. Specifically, the study first analyzes changes in City Q residents’ perceptions of seafood consumption and explores the association between these changes and nuclear wastewater discharge. Through two rounds of surveys, the study evaluates shifts in consumer purchasing power for seafood and changes in awareness of nuclear wastewater before and after its arrival in City Q. Secondly, by combining the Difference-in-Differences (DID) model with the Seasonal Autoregressive Integrated Moving Average (SARIMA) model, the study conducts iterative training and analysis on existing data from the National Bureau of Statistics to forecast cumulative growth rate changes in seafood industry sales in City Q and a control city (City J) over the next five years under the impact of nuclear wastewater. These findings provide relevant government departments with effective countermeasures and risk forecasts, carrying substantial practical significance and policy guidance value.

2. Theory and Method

2.1. Research Principles

The questionnaire for this study was designed to investigate respondents’ awareness, attitudes, and perceived impacts of Country J’s nuclear wastewater discharge incident on local seafood consumption and industry. “Fogwater deposition played a significant role in spreading radiocesium across forested areas, contributing to regional radioactive contamination” (Imamura et al., 2020) [9]. It also aimed to understand whether respondents would consider the impact of the nuclear wastewater incident when purchasing local seafood and to assess any changes in seafood consumption after the event. Two rounds of surveys were conducted: one in March, before the nuclear wastewater reached City Q, and another in October, after its arrival. Through comparative analysis of the data from these two surveys, we examined how subtle changes indirectly influenced the seafood industry’s sales in City Q.

The first questionnaire survey was conducted through a combination of online and offline channels. The online survey was distributed via the “Tencent Questionnaire” platform, with targeted distribution in City Q, City J, and City W. Using the “sample service” feature on the Tencent Questionnaire platform, we launched the survey in these three cities, with quotas set at 120 responses for City Q, 80 for City J, and 50 for City W, resulting in a total of 257 responses. Offline, team members conducted on-site surveys in high-traffic areas of City Q and City J, collecting 90 valid questionnaires across three teams. After aggregating both online and offline data, we gathered a total of 347 questionnaires. Analysis of the responses revealed that 37 responses from the online survey came from residents of cities outside the focus areas, such as City Z (5 responses) and City Y (5 responses). Since this study only considered data from City Q, City J, and City W, responses from other regions were excluded. Overall, the response rate for the first survey was 89.3% (310/347). The second survey was distributed solely through the online “Tencent Questionnaire” platform, again targeting City Q, City J, and City W, with the same distribution quotas as the first survey (120 for City Q, 80 for City J, and 50 for City W). A total of 275 responses were collected. Among them, 43 responses came from respondents in cities outside the three targeted cities, such as City Y (15 responses) and City N (8 responses). After excluding these responses, 232 valid responses remained, with 43 deemed invalid, yielding a response rate of 84.4% (232/275) for the second survey. To ensure the reliability and interpretative accuracy of the questionnaire results, data preprocessing and reliability analysis were conducted based on the collected responses. First, the data was quantified and graded according to respondents' purchasing power, on a scale of 1 to 5, as shown in Table 1.

Table 1. Questionnaire Scale

Question No.	Option Letter	Option Value	Score
2	A	Strongly Disagree	1
	B	Somewhat Disagree	2
	C	Neutral	3
	D	Somewhat Agree	4
	E	Strongly Agree	5
3	A	Yes, Would Consider	1
	B	No, Would Not Consider	2
4	A	Yes, Reduced	1
	B	No, Not Reduced	3
	C	Unchanged Quantity, but More Cautious	2
5	A	Very Large	1
	B	Large	2
	C	Average	3
	D	Small	4
	E	No Impact	5
7	A	Yes, Will Choose Local Seafood	2
	B	No, Will Not Choose Local Seafood	1
	C	Indifferent	1.5
8	A	Yes, Will Stop	1
	B	Yes, Will Reduce	2
	C	No, Will Not Stop or Reduce	3
9	A	Yes, Will Stop	1
	B	Yes, Will Reduce	2
	C	No, Will Not Stop or Reduce	3
10	A	Very Worried	1
	B	Somewhat Worried	2
	C	Neutral	3
	D	Somewhat Optimistic	4
	E	Very Optimistic	5

Afterward, we conducted a Cronbach's alpha test to assess the overall reliability of the questionnaire, as shown in Table 2 below:

Table 2. Questionnaire Feasibility Test Results

	Q2	Q3	Q4	Q5	Q7	Q8	Q9	Q10
Mean μ	1.09	1.08	1.46	1.64	1.37	1.71	1.52	1.40
Standard Deviation S	0.39	0.27	0.67	0.81	0.48	0.54	0.53	0.63
Variance S^2	0.15	0.07	0.44	0.65	0.23	0.30	0.28	0.40
Sum of Sample Variances $\sum_{i=1}^{8} S_i^2$	2.53							
Number of Test Questions K	8							
Total Variance S_x^2	7.36							
Reliability α	0.75							

In this analysis, Questions 1 and 6 were excluded. The reason for excluding Question 1 is that responses were relatively uniform, offering little variance for analysis. Question 6 was a conditional logic question, which could only be answered if respondents selected an "affected" option in Question 5, making it less generalizable. The reliability was calculated using the Cronbach's alpha method, with the specific formula as follows:

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum S_i}{S_x^2}\right) \tag{1}$$

By observing the reliability score, we note that a Cronbach's alpha of 0.75 is generally considered quite good for survey questionnaires. This indicates that the overall design of the questionnaire is sound, with strong internal consistency among the items. Moreover, the appropriate methods used during the survey process have enhanced the credibility of the data, laying a solid foundation for subsequent data analysis.

2.2. Research Methods

2.2.1. Difference-in-Differences (DID) Model

According to the theoretical assumptions of the Difference-in-Differences (DID) model:

$$Y_{it} = \beta_0 + \beta_1 \mathrm{Treat}_i + \beta_2 \mathrm{Post}_t + \beta_3 \mathrm{Treat}_i \times \mathrm{Post}_t + \eta' x_{it} + \epsilon_{it} \tag{2}$$

Where i represents the individual, t denotes the time period, and $Treat$ is the group dummy variable: if the individual i belongs to the treatment group,$Treat = 1$; otherwise, $Treat = 0$. $Post$ is the time dummy variable: if the time period t is before the policy implementation, $Post = 0$; if it is after the policy implementation, $Post = 1$. $Treat * Post$ is the interaction term, and its coefficient represents the net effect of the policy implementation. The remaining variables can be explained as shown in the following Table 3:

Table 3. Effect Relationships

	Before policy implementation	After policy implementation	Difference
Treatment group	$\beta_0 + \beta_1$	$\beta_0 + \beta_1 + \beta_2 + \beta_3$	$\beta_2 + \beta_3$
Control group	β_0	$\beta_0 + \beta_2$	β_2
Difference	β_1	$\beta_1 + \beta_3$	β_3

2.2.2. SARIMA Model

The general form of the SARIMA model is:

$$\Phi(B^s)\phi(B)\nabla^d \nabla_s^D Y_t = \Theta(B^s)\theta(B)\varepsilon_t \tag{3}$$

Where Y_t represents the time series data; B is the lag operator; and ϵ_t denotes the white noise term. Non-seasonal component:

$$\begin{cases} \phi(B) = 1 - \phi_1 B - \cdots - \phi_p B^p \\ \theta(B) = 1 + \theta_1 B + \cdots + \theta_q B^q \\ \nabla^d = (1 - B)^d \end{cases} \tag{4}$$

Seasonal component:

$$\begin{cases} \Phi(B^s) = 1 - \Phi_1 B^s - \cdots - \Phi_P B^{Ps} \\ \Theta(B^s) = 1 + \Theta_1 B^s + \cdots + \Theta_Q B^{Qs} \\ \nabla_s^D = (1 - B^s)^D \end{cases} \tag{5}$$

This paper employs a combined approach of comparative surveys and the DID-SARIMA model for prediction. The comparative survey primarily collects data on changes in seafood purchasing intentions among City Q residents before and after the arrival of nuclear wastewater. The DID model's first part is based on real data obtained from the Bureau of Statistics, while the latter part integrates SARIMA model predictions, resulting in an analysis of the cumulative growth rate in seafood industry sales in City J and City Q over a 10-year period, reflecting changes influenced by nuclear wastewater.

3. Data Analysis

3.1. Survey Results

Through two rounds of questionnaires, we conducted an in-depth analysis of seafood consumption behavior among residents in three cities (Qingdao - City Q, Weifang - City W, and Jinan - City J) under the context of nuclear wastewater discharge. By comparing and interpreting the differences in data from the two surveys, we can draw further conclusions. On one hand, as shown in Figure 1 above, the proportion of residents in the three cities who reduced seafood consumption increased across both surveys, while the proportion of those who did not reduce seafood consumption decreased. This suggests a decline in seafood consumption over time, influenced not only by repeated nuclear wastewater discharge but also potentially by market supply and demand, as well as individual dietary habits. On the other hand, as shown in Figure 2, the proportion of people who believe that nuclear wastewater discharge has a “very large” impact on seafood has decreased. Except for City W, the combined proportion of those choosing “large” and “very large” impact has also declined. The two surveys mainly reflect a reduction in public anxiety over nuclear wastewater, possibly due to a decrease in recent news reports on the topic. Additionally, public views on this issue have become more dispersed, potentially influenced by a wider range of information sources.

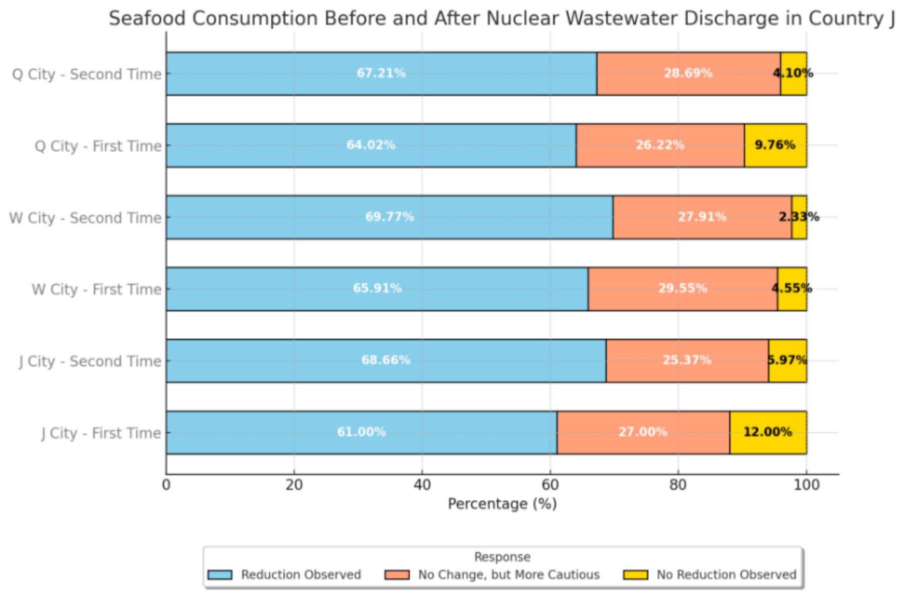

Figure 1. Seafood Consumption Before and After Nuclear Wastewater Discharge in Country J

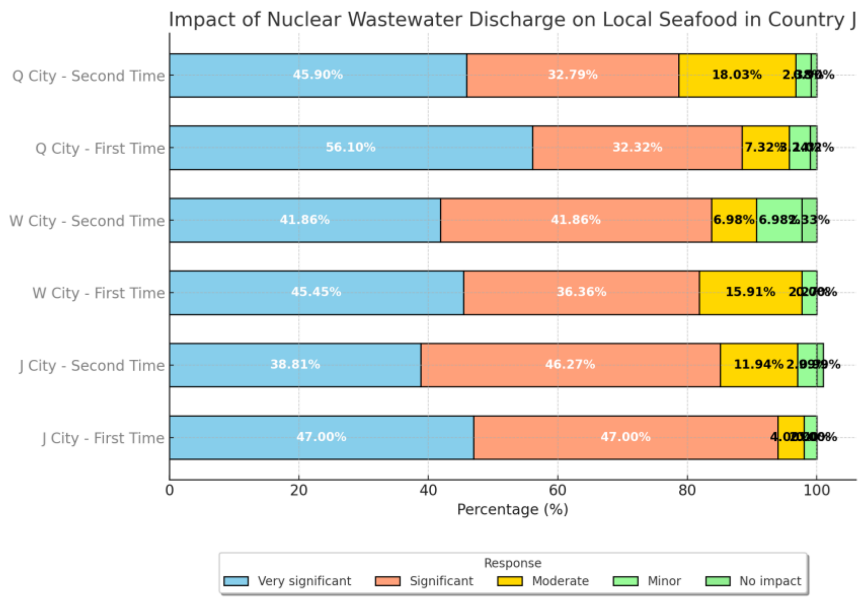

Figure 2. Impact of Nuclear Wastewater Discharge on Local Seafood in Country J

Additionally, as shown in Figure 3 above, considering the impact of Country J’s nuclear wastewater on the local seafood industry, the proportion of residents who would choose alternative products (such as agricultural products or seafood from other regions) remains above 90%, with no significant regional or temporal differences. However, the proportion of those who chose to "completely replace" local seafood products has noticeably declined, with a 48.96 percentage point drop in City Q. This indicates that while residents are still highly concerned about food safety, there is a slight relaxation in their stance, likely influenced by information from news reports and other sources. As shown in Figure 4, through a comparison of the three regions, it was found that residents of City W are more likely not to purchase local seafood, with the rates in City Q and City J being roughly consistent. Residents who decide to continue purchasing seafood are more prevalent in City Q, followed by City J and then City W, with a small proportion of indifferent residents in all three cities. The factors contributing to this phenomenon include: (1) Information dissemination and public education have played a crucial role in this context. Media reports on the effects of nuclear wastewater and expert interpretations significantly influence public purchasing behavior. Providing reliable safety information significantly affects consumer fears regarding contaminated seafood" (Wakamatsu and Miyata, 2021) [10]. If the information received by the public is rational and scientific, excessive panic may be mitigated, reducing its impact on purchasing behavior.

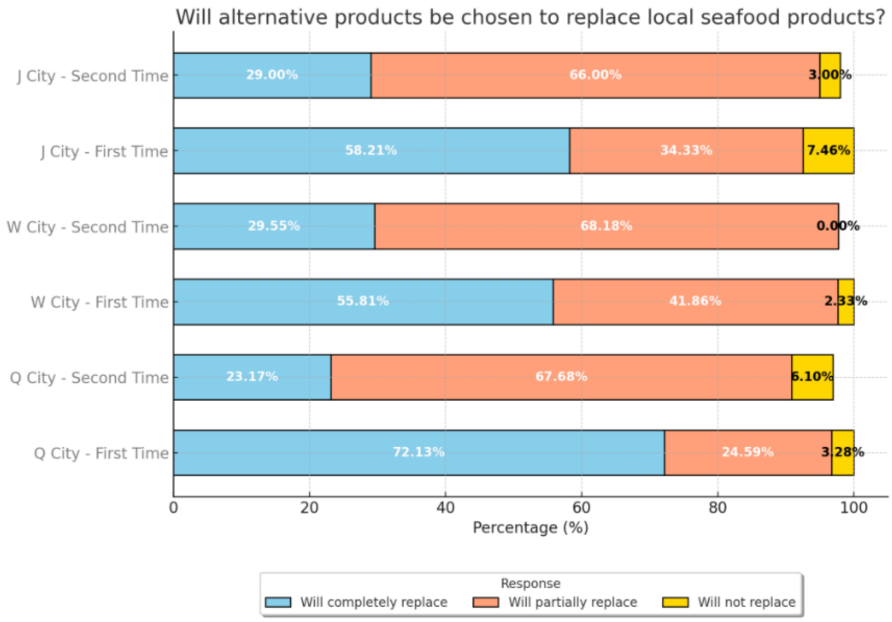

Figure 3. Preference for Alternative Products Over Local Seafood After Nuclear Wastewater Discharge

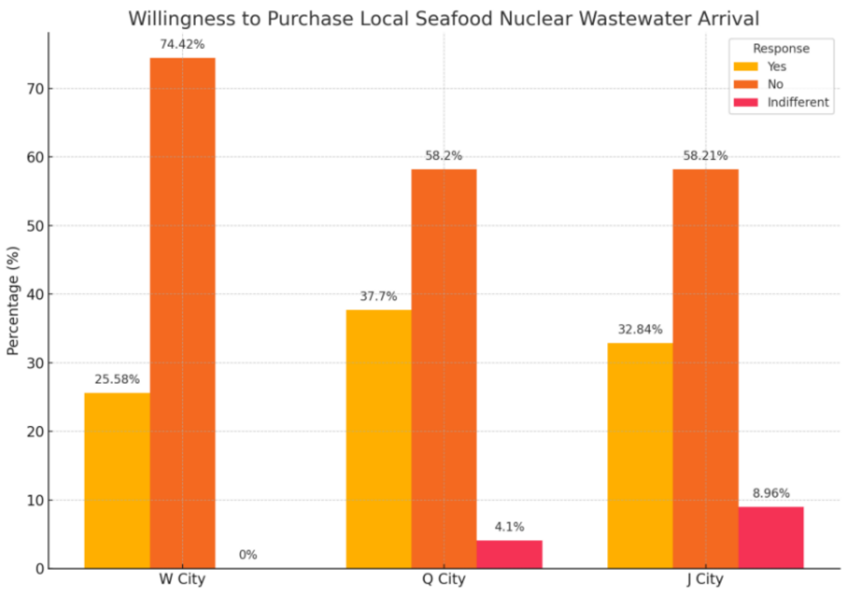

Figure 4. Willingness to Purchase Local Seafood Nuclear Wastewater Arrival

(2) Government regulation and safety certification are also important factors influencing consumers’ purchasing decisions. If the government can promptly release authoritative monitoring data proving the safety of local seafood, it will help maintain consumer confidence. (3) The availability of substitutes in the market, such as freshwater fish or other protein sources, may also lead consumers to choose these alternatives, thereby reducing demand for potentially contaminated seafood. Price fluctuations cannot be ignored either. Nuclear wastewater discharge may lead to a reduction in the supply of certain seafood products, which in turn affects prices. Price increases or fluctuations will directly impact consumers’ willingness to purchase. (4) Social psychological factors also play a role. Consumer psychology and social behavior affect purchasing decisions. For example, when people around them begin stockpiling seafood or other food items, individuals may be influenced by herd mentality and adjust their purchasing behavior accordingly.

3.2. Model Results

In establishing this model, City J was selected as the control group and City Q as the treatment group. Monthly cumulative seafood market sales data for City J and City Q from 2019 to 2023 were collected from the statistical bureaus of each city and categorized by year. First, key properties such as normality and homoscedasticity of the sales data were tested. The residual analysis revealed the following: residuals showed significant fluctuations when the fitted values were low, and also displayed considerable fluctuation at high fitted values, possibly indicating heteroscedasticity or that the model might not fully capture the data characteristics; the residuals overall approximated a normal distribution; the square root of the residuals tended to increase with higher fitted values, suggesting potential heteroscedasticity; while most points fell within a reasonable range, a few points were near or exceeded the Cook’s distance line, potentially indicating a substantial influence of these points on the model. Overall, this regression model performed reasonably well but exhibited certain issues. Next, modeling and a parallel trend test were conducted, with a focus on the coefficient of “treated_time”. If the coefficient of “treated_time” is not significant, it indicates that the trends of the treatment group and control group were similar before the intervention, satisfying the parallel trend assumption.

Source	SS	df	MS			
				Number of obs	=	10
				F(3, 6)	=	15.92
Model	13744.7783	3	4581.59278	Prob > F	=	0.0029
Residual	1727.20667	6	287.867778	R-squared	=	0.8884
				Adj R-squared	=	0.8325
Total	15471.985	9	1719.10944	Root MSE	=	16.967

outcome	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
treated_time	27.93333	15.48838	1.80	0.121	-9.965359	65.83203
treatment	31.63333	13.85323	2.28	0.063	-2.264288	65.53095
treated_post	45.96667	21.90387	2.10	0.081	-7.630178	99.56351
_cons	25.86667	9.79571	2.64	0.039	1.897429	49.8359

Figure 5. Test results of differential model

As shown in Figure 5, the p-value of the coefficient for “treated_time” is 0.121 (greater than 0.05), so we cannot reject the parallel trend assumption, meaning that before the intervention, the trends of the treatment and control groups can be considered parallel. Therefore, based on this regression result, the data meets the parallel trend test. Data before and after the policy announcement was selected, with time on the horizontal axis and the average (cumulative) sales amount on the vertical axis. For ease of observation and plotting, Jinan’s growth rate prior to the discharge was aligned with Qingdao’s growth rate. As shown in Figure 6, in the five-year forecast, the cumulative growth rate of sales in City Q tends to stabilize, growing at a fixed cycle and rate each year, though with a slight decline in growth compared to previous years. City J’s growth rate also stabilizes, but the overall gap between City Q and City J continues to widen. In summary, the sensitivity of the SARIMA model is reflected in its ability to capture seasonal variations, its flexibility in parameter selection, and its adaptability, making the final forecast results relatively accurate. The impact of these predictions on the preliminary DID model is as follows: City Q's growth rate remains higher than City J's but has slowed slightly, falling between the original growth rates of both cities. This indicates that over time, the discharge of nuclear wastewater may have a negative impact on the cumulative growth rate of City Q's seafood industry sales, though the effect is minimal. Model analysis shows that while the growth in City Q's sales is affected by nuclear wastewater, the overall growth rate remains stable and exhibits seasonal fluctuations. City Q's cumulative growth rate was already higher than City J's before the nuclear wastewater impact; therefore, despite the influence, City Q's economic growth rate is still faster than City J's, and the gap between the two may continue to expand.

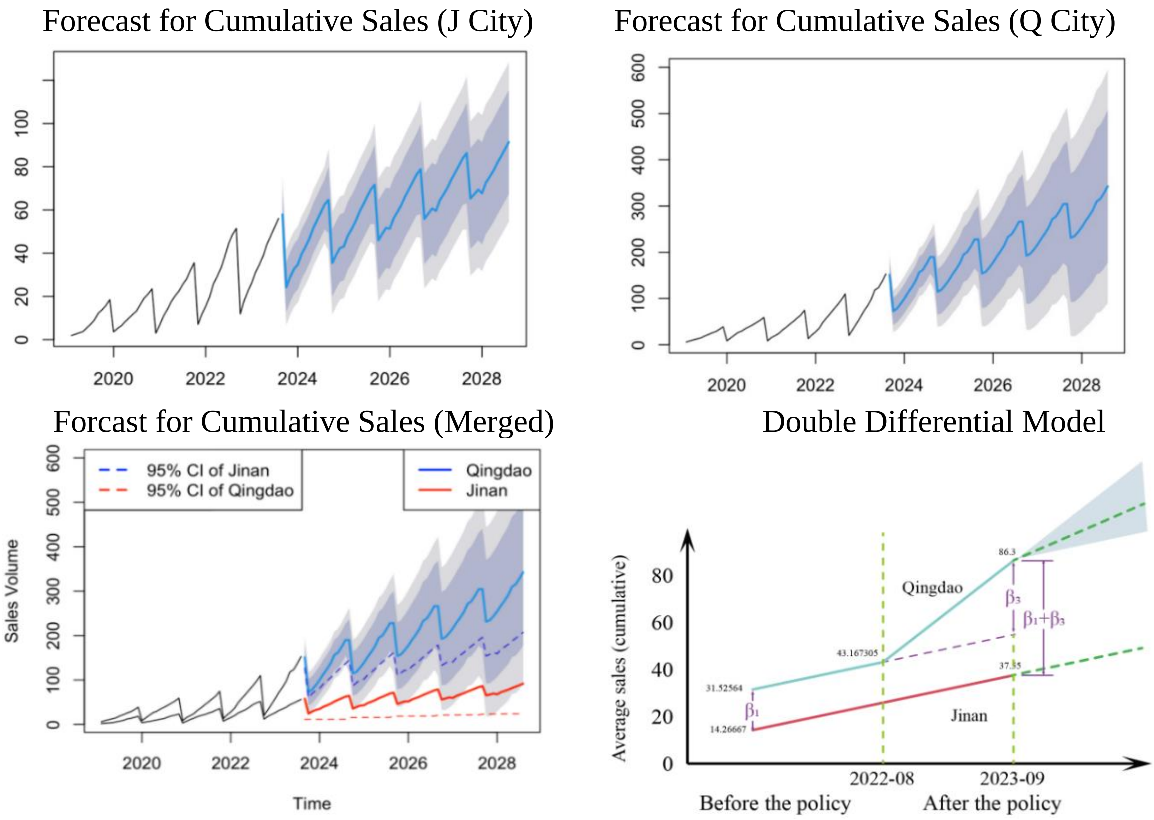

Figure 6. Model prediction results show and influence on DID model

4. Conclusion

Through comparative surveys, the SARIMA model, and the DID model, this paper finds that, on one hand, Country J's discharge of nuclear wastewater does indeed have some impact on the seafood industry in neighboring City Q, though the negative impact is minimal. On the other hand, City Q's residents are greatly affected by Country J's discharge of nuclear wastewater, directly influencing seafood sales in City Q.

Based on these conclusions, this paper proposes the following recommendations: (1) Strengthen inspection and quarantine of imported and local seafood products to ensure food safety standards comply with national and international regulations. (2) Establish a long-term monitoring mechanism for marine environment and seafood quality, promptly releasing test results to improve transparency. (3) Collaborate with international food safety organizations to jointly monitor the impact of nuclear wastewater on marine ecology and obtain authoritative data. (4) Invite authoritative experts and scholars to conduct public lectures and media interviews to address public concerns and alleviate unnecessary panic. (5) Share successful experiences from other regions in handling similar issues to boost public confidence. (6) Collaborate with businesses to launch promotional campaigns for seafood products to increase consumer interest. (7) Improve the quality and service of seafood products to enhance consumer satisfaction. (8) Diversify seafood product options by providing more safe and high-quality choices to meet various consumer demands. (9) Strengthen laws and regulations related to food safety, strictly crack down on illegal activities, and maintain market order.

Although the selection and application of the two models in this study are not optimal and involve certain idealized assumptions, the results still offer valuable preliminary insights. The models demonstrate how seafood sales trends might respond to factors like food safety concerns, regulatory actions, and environmental changes. These insights can serve as a foundation for guiding initial decisions and strategies. However, given that these models simplify real-world complexities, they may not fully capture all factors impacting seafood sales, potentially leading to discrepancies between predicted and actual outcomes. Therefore, while the current models provide a practical starting point for understanding trends, they should be seen as part of an iterative process. With refinements in model selection and an expansion to multi-parameter approaches in future research, this study's framework can evolve to offer increasingly accurate and applicable results in real-world settings.

References

[1] Bezhenar R, Takata H, De with G, et al. Planned release of contaminated water from the Fukushima storage tanks into the ocean: Simulation scenarios of radiological impact for aquatic biota and human from seafood consumption [J]. *Marine Pollution Bulletin*, 2021, 173: 112969.

[2] Wang M, Tan Z, Liu J, et al. Analyzing the impact of Fukushima nuclear wastewater discharge on seafood trade with gravity model [J]. *Ocean & Coastal Management*, 2022, 230: 106302.

[3] Li, J. Analysis of the Impact of Japan's Nuclear Wastewater Discharge on the Seafood Market in Neighboring Regions [J]. *China Fisheries Economics,* 2012.

[4] Wei Y, Zhang J, Cao X, et al. Fukushima's radioactive water threatens coastal groundwater [J]. *Environmental Science & Technology,* 2024.

[5] Chun-Chang L, Chi-Ming L, Hui-Chuan H. The impact of a mass rapid transit system on neighborhood housing Prices: An application of Difference-In-Difference and Spatial Econometrics [J]. *Real Estate Management and Valuation*, 2020, 28 (1): 28 – 40.

[6] Lu, L., Yang, W., & Huang, Z. Study on the Impact of Japan's Nuclear Wastewater Discharge on China's Aquatic Product Imports and Exports and Countermeasures [J]. *China Business Theory,* 2024, 2024 (9): 57 - 61.

[7] Wing C, Dreyer M. Making sense of the Difference-in-Difference design [J]. *JAMA Internal Medicine*, 2024, 184 (10): 1250.

[8] Caniglia E C, Murray E J. Difference-in-Difference in the Time of Cholera: A Gentle Introduction for Epidemiologists [J]. *Current Epidemiology Reports*, 2020, 7 (4): 203 – 211.

[9] Imamura N, Katata G, Kajino M, et al. Fogwater deposition of radiocesium in the forested mountains of East Japan during the Fukushima Daiichi Nuclear Power Plant accident: A key process in regional radioactive contamination [J]. *Atmospheric Environment*, 2020, 224: 117339.

[10] Wakamatsu H, Miyata T. Effects of radioactive safety information on consumer fears of radioactive contamination from oyster products in Japan [J]. *Marine Policy*, 2021, 126: 104401.