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Original Paper

Towards Effective Measures for Curbing the Illegal Wildlife Trade: A Comprehensive Approach with ARIMA Modeling and Responsible Party Evaluation

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Abstract

Illegal wildlife trade has become an urgent global problem that threatens global ecosystems, biodiversity and sustainable development. This problem requires us to propose comprehensive measures to significantly curb illegal wildlife trade.We used data from government work reports from 2014 to 2023 to establish an evaluation system for the responsible parties, and found that wildlife conservation is very important to the Chinese government using the AHP-Entropy weight method. We developed relevant measures to reduce illegal wildlife trade based on Citespace's literature research method. Then we collected public data from Chinese governmental departments from 2010 to 2023, and used ARIMA model to predict the future of the initiatives we developed to reduce illegal wildlife trade. By collecting public data from the China Wildlife Wildlife Enforcement Agency and fitting the state of wildlife conservation based on China's national conditions over the past 15 years, we evaluated the available resources and found that while the overall trend of the Chinese government can reduce illegal trade practices, the trend is not stable in the short term. China's wildlife protection agencies can continue to increase enforcement of this problem to better reduce the occurrence of illegal wildlife trade behavior.

Keywords

illegal wildlife trade, AHP-Entropy weight method, TF-IDF, word vector analysis, ARIMA

1. Introduction

The illegal wildlife trade is positioning it as the fourth largest illicit trade globally. This illicit activity has emerged as a pressing global concern, posing threats to global ecosystems, biodiversity, and sustainable development (*Why Should We Care about Wildlife Trafficking?*, n.d.).Consequently, urgent and coordinated efforts worldwide are imperative to address its extensive impacts. The objective of the task at hand is to propose comprehensive measures that aims to substantially reduce the illegal wildlife trade. Given the complexity of combating illegal wildlife trade, which necessitates collaboration and unwavering commitment, we believe that the optimal client for these measures would be a government agency or an international organization(*International Monetary Fund*, n.d.).Such entities possess the requisite authority, resources, and dedication to enforce measures aimed at combating illegal wildlife trade.

2. Looking for the Fitting Responsible Party

If the measures we propose to protect wildlife are to be effectively implemented, it is essential to find the right people to be held accountable for carrying out this meaningful and difficult task. Although it may seem like protecting wildlife should be a global effort, it always needs someone to take the first step. Looking for the fitting responsible party can make a significant difference. In this case, after finding the best responsible object to undertake this task, we will prove that our choice of object is reasonable and correct from different perspectives.

Table 1. Notations

Symbols	Description	Unit
QWT	Quantity of wildlife traded	KG
ICYMSP	Ivory calendar year market selling prices	$\mathrm{YUAN} \cdot \mathrm{KG}^{-1}$
Budget	Budget	YUAN
NCC	Number of conviction cases	-
NAL	Number of articles of law	-
PPD	Propaganda	YEAR^{-1}
ASAE	The average annual search volume of wild animal entries	-
CI	Corruption index	-
GDP	Gross domestic product	$\times 10^9$ \$
TISD	Total investment in sustainable development	$\times 10^9$ \$
TI	Terrorism index	-
PGDG	The proportion of government debt in GDP(%)	-
T	Temperature	$^\circ$C

NIT	Number of illegal trade	-
GDP	Gross domestic product	$\times 10^9$ $
NAL	Number of articles of law	-
TISD	Total investment in sustainable development	$\times 10^9$ $
NCFI	Number of convictions in the first instance	-
RI	Mean consistency index	-
CR	Consistency index	-
r_{ij}	The characteristic ratio of the evaluation index matrix	-
S_j	Evaluation index information entropy	-
V_j	Objective weights of evaluation indicators	-
a_j	The sum weight calculated by the AHP-entropy weight method	-
P_j	AHP analysis of the calculated subjective weights	-

2.1 AHP-Entropy Weight Method to Evaluate the Responsible Party

The fight against illegal wildlife trade is a complicated issue that demands collaboration and commitment. Therefore, it is essential to choose a suitable client with adequate power, resources, and genuine interest in effectively implementing the required measures. Power provides enforcement, resources provide sustainability and interest and motivation provide intrinsic motivation. We use fixed indicators like power, resources, interests, and motivation to select appropriate potential clients. We construct a model using the Analytic Hierarchy Process (AHP)-entropy weight method and TF-IDF model. These models help us to select suitable potential customers using a scientific approach.

To establish a client selection system, it is essential to have a clear set of evaluation criteria to help select the proper wildlife protection agencies. We have identified four key indicators that will help us in this process. These indicators are the government's interest, power, resource allocation, and intent towards global wildlife conservation. To ensure that the indicators are evaluated objectively, we are using the AHP-entropy weight method. This method will help us to assess the best clients suitable for our project while considering the uncertainty and subjective judgment of the indicators.

We selected four representative international and non-international government organizations, including the United Nations Environment Program (UNEP), the World Wildlife Fund (WWF), Interpol (International Criminal Police Organization), and the National Wildlife Enforcement Agency (NWEA), as potential customers to analyze.

To ensure a clear and convincing correlation between indicators, it is essential to develop a hierarchy of indicators and distinguish between their levels of importance. To achieve this, we consulted with national government agency consultants specializing in wildlife protection and illegal wildlife trade. We also invited five experts to score the score table we developed and consulted relevant literature to ensure the rationality of the score. We used the Analytic Hierarchy Process (AHP) to calculate the

relevant weights among the indicators.

The consistency test is performed through matrix operations. If $CR < 0.1$, the characteristic value becomes the objective weight of the evaluation index.The calculation formula is as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{CR} \tag{2}$$

After solving the previous eigenvector, we calculate the consistency index (CI). By determining the corresponding mean consistency index (RI), we can calculate the consistency ratio (CR). We applied this method to five sets of evidence and found that the results passed the consistency test.

We need to quantify the indicators based on data to determine the objective weights related to our evaluation indicators. First, we need to construct the evaluation indicator matrix $A = (X_{ij})_{m \times n}$. Then the index feature ratio is calculated. Calculate the information entropy of the corresponding index S_j. Finally, the corresponding index weights are calculated:

$$r_{ij} = \frac{bij}{\sum_{i=1}^{m} b_{ij}} \tag{3}$$

$$S_j = -(\ln m)^{-1} \sum_{i=1}^{m} r_{ij} \ln r_{ij} \tag{4}$$

$$V_j = \frac{1 - S_j}{\sum_{j=1}^{m} (1 - S_j)} \tag{5}$$

The entropy weight method is used to modify the subjective weight and the subjective weight and objective weight are coupled to obtain the comprehensive weight to consider the uncertainty and subjective judgment between indicators:

$$a_j = \frac{V_j P_j}{\sum_{j=1}^{n} (V_j P_j)} \tag{6}$$

After following the steps mentioned above, we have developed a comprehensive system for evaluating wildlife conservation agencies in five representative countries based on customer needs. This system assigns weights to different factors and provides strong support for clients in decision-making by ensuring that the selected agency is the best fit for their project. By calculating the weights, we can obtain results that will help select the most suitable organization.

Table 2. Weighting Results

Indicators	Indicator weight	UNEP	WWP	ICPO	NWEA
Interests	0.2998	0.2941	0.2441	0.1765	0.2953
Benefits	0.3538	0.2273	0.1725	0.1875	0.3365
Power	0.2123	0.2353	0.2941	0.2353	0.2953

Resources	0.1341	0.2353	0.2941	0.2353	0.2953

Through the weighted calculation of the weight coefficient, the calculation results show that we believe that NWEA (National Wildlife Enforcement Agency) meets the comprehensive index evaluation results we need for our project content. Next, we will use the TF-IDF model to further determine which country's wildlife protection agency is most suitable for our clients.

2.2 TF-IDF to Evaluate the Responsible Party

We evaluated five representative countries (China, the United States, Australia, Brazil, and Canada) based on their performance in the past ten years (2014-2023) (*International Monetary Fund*, n.d.). We conducted a detailed analysis using word vector analysis and the TF-IDF model.

To measure the global power, resources, and intentions and interests of governments in wildlife conservation, six query segments were constructed:

The government's active participation in international conventions and treaties related to wildlife protection demonstrates its commitment and global leadership in combating illegal wildlife trade.

The government's substantial allocation of funds towards strengthening law enforcement capacities and implementing conservation measures underscores its dedication to protecting wildlife and combating illegal wildlife trade globally.

Due to space limitations, they will not be listed one by one here. After the six query segments are sent to TF-IDF, the model analysis results are as follows:

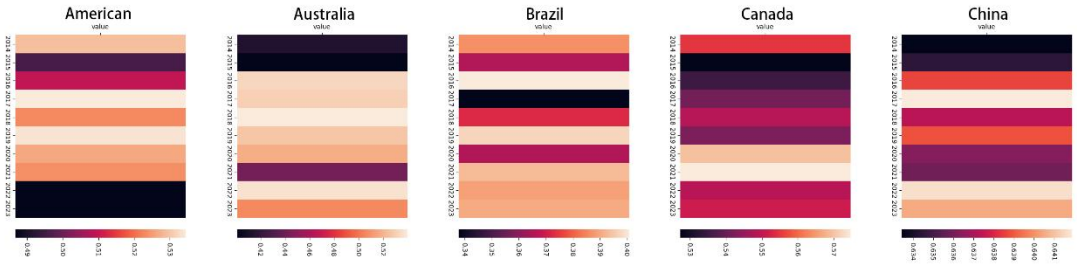

Figure 1. Heat Map Representation of TF-IDF Results

We created a word cloud graph to validate the accuracy of the word vector analysis method:

Figure 2. Word Cloud of Five Countries

According to the data illustrated in Figure 2, the United States has not mentioned much to wildlife protection in the last two years, resulting in a low average value. On the other hand, Australia, Brazil, and Canada have consistently shown some level of concern towards wildlife protection. Even though their attention has increased in the past five years, their actual contribution is not very significant due to the low average value. Conversely, China has always recognized the importance of wildlife protection and has continued to invest in it. China's efforts have intensified in recent years, resulting in a higher average value.

Based on the TF-IDF model analysis results, we can conclude that China has the highest correlation with the query field in 2017, 2022, and 2023. The correlation values for these years are 0.6419, 0.6416, and 0.6405, respectively, with an average of 0.6413 for the top three countries. This indicates that the Chinese government's approach to wildlife protection is the most similar to the characteristics we evaluated. Therefore, the Chinese government prioritizes wildlife protection, making them the most reliable clients.

2.3 CiteSpace to Prove the Result

In order to prove that our choice of responsibility object is reasonable and correct, we conducted an in-depth analysis of the relevant literature and China's national conditions. We used the keyword "Illegal Wildlife Trade""China" to search the core database of the Web of Science, which resulted in 1223 literature records. We then screened these records based on the critical information related to our measures. Finally, we imported 930 documents into CiteSpace for literature visualization analysis (Figure 3)(*Find out More about CiteSpace | SourceForge.Net*, n.d.).

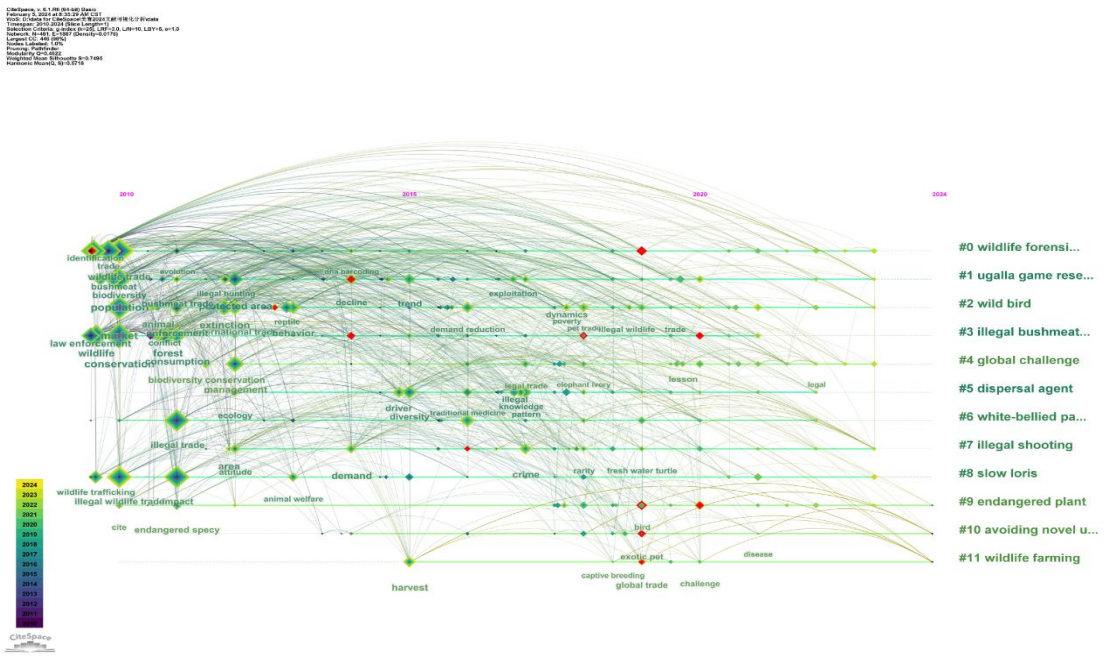

Figure 3. Citespace's Timeline Mapping

There are many essential words related to the topic of "Illegal Wildlife Trade", including "Wildlife Market" and "Trans-national Illegal Pangolin Trade". This trade has a significant impact on the world, and studies have shown that there is a significant import and export of illegal wildlife products, such as pangolin, tiger bone wine, ivory, sea turtles, African rhinos, and others, from Southeast Asia.

From 2006 to 2013, China experienced a severe problem with the illegal trade of imported products, particularly in regard to wildlife. This has led to an increase in the production of endangered wildlife. As a result, relevant organizations such as the United Nations have started to pay more attention to the situation.What's worse, the illegal wildlife trade has seriously damaged the ecosystem, destroyed biodiversity, and run further counter to the concept of sustainable development, and human beings are gradually swallowing the dire consequences of their own(Maher & Sollund, 2016). Time map analysis shows that zoonotic blood pathogens and other emerging pathogens and viruses are seriously endangering human life and health, such as the outbreak of COVID-19 and the wildlife market, leading to a global health crisis shows the seriousness of the problem(van Uhm et al., 2021).

China is a country that has cracked down on illegal wildlife trade crimes. Through access to materials released by the Chinese government, we learned that our measures coincide with the thinking of the Chinese government (*Wildlife Protection Law of the People 's Republic of China*, n.d.). From the perspective of China's national conditions, drug trade, firearms, and human trafficking are all criminal acts with egregious circumstances, extremely serious crimes, and extremely bad social impact. The Chinese government is strictly opposed to these acts. According to the relevant data, criminal groups engaged in illegal wildlife trafficking are also likely to engage in drug, gun, human trafficking, and other criminal industries, so it is necessary to combat illicit wildlife trade, which means that it is required to implement the initiatives issued by our measures.

The Chinese government has long emphasized the importance of preserving natural resources with the slogan, "Lucid waters and lush mountains are invaluable assets" (*Lucid Waters and Lush Mountains Are Invaluable Assets - China - Chinadaily.Com.Cn*, n.d.). However, the illegal wildlife trade significantly threatens species diversity and ecosystem health. To combat this problem, we believe the Chinese government should collaborate with us to slow the loss of species and reduce the negative impact of illegal animal trade on ecosystems (Zhu, n.d.).

The Chinese government has paid a hefty price in the battle against influenza diseases, such as the Ebola virus and SARS virus, and is well aware of their harmful impact. Studies show that illegal wildlife trade is connected to the transmission and origin of these viruses, and three-quarters of acute infectious diseases are driven by illicit animal trade as one of the factors(Duffy, 2016). The Chinese government is keen to fight disease and safeguard its people, as evidenced by its efforts to battle influenza diseases like Ebola. This is why it's crucial for the Chinese government to collaborate with us.

The Chinese government has proposed building a global community with a shared future for all (*Building a Community of Shared Future for Mankind : China 's Initiatives and Actions*, n.d.). The

illegal wildlife trade is often a worldwide, complex, and interconnected issue. As a major country, China has a significant responsibility to address the problems that threaten global peace and stability. Therefore, China should take action to combat the illegal wildlife trade.

3. Predicting Model Establishment

Based on Citespace's literature research methodology described above, we have formulated the following initiatives that will help China's Wildlife Enforcement Agency to reduce illegal wildlife trade:

1. Enhance legal measures, enforcement policies, and supply chain controls.
2. Decrease the demand for illegal wildlife products.
3. Strengthen international collaboration and coordination.
4. Develop a robust monitoring and evaluation system to evaluate the progress and impact of the project.

To ensure that our proposed measures are effective, it's crucial to have accurate and reliable predictions of their effects. To achieve this, we must select one or more measurable influencing factors. We have chosen to use the linear regression model and the ARIMA time series forecasting model to measure the impact of the proposed measures jointly.

It is difficult to estimate the number of wild animals traded worldwide accurately, and the prices of wild animals sold in the market fluctuate unstablely from month to month. Market demand, consumer behavior, and corresponding budgets for enforcement efforts vary significantly between countries. Given this, we will focus on China for in-depth research to demonstrate the feasibility and applicability of this solution.

3.1 Preparing for Model Establishment

We collected the following datasets in Table 2, as we are unable to present the entire data set due to space limitations.

Table 3. Datasets for Predicting

Year	QWT	ICYMSP	Budget	NCC	NAL	PPD	ASAE
2010	1134429	2450	1004967	34	61	1	256
2011	1057056	5250	1004268	27	61	3	381
2012	3779448	12372	1504447	45	62	2	426
			...				

We first use a linear regression model to evaluate the impacts on QWT and ICYMSP. After analysis, we selected wildlife trade volume (QWT) and wildlife trade price as two dependent variables. Profitability will make people take risks to reflect the illegal wildlife trade in this period in a macroscopic way—the

trend of the black market. We also select two independent variables: the intensity of law enforcement and the intensity of publicity, which can measure the effect of the model from the perspective of enforcement or non-enforcement.

3.2 Model Establishment

3.2.1 Linear Regression Model

The following is our linear regression model:

Table 4. Model Summary

	R	R Square	Adjust R Square	Std. Error of Estimate	Sig .F Change	DW
QWT	0.512	0.262	-0.199	2157853	0.723	1.836
ICYMSP	0.474	0.224	-0.26	4265.136	0.794	1.994

Table 5. Coefficient Summary

	DV	UB	SE	Sig.	S.VIF
Constant	QWT	-1016036	26335433	0.97	
	ICYMSP	3611.821	52053.688	0.946	
Budget	QWT	-0.7	1.415	0.034	2.109
	ICYMSP	-0.001	0.003	0.048	2.109
NCC	QWT	18162.481	13443.532	0.014	1.77
	ICYMSP	27.25	26.572	0.035	1.77
NAL	QWT	43578.243	441936.18	0.424	1.75
	ICYMSP	66.35	873.515	0.941	1.75
PPD	QWT	-1520.611	2587.466	0.573	1.422
	ICYMSP	-6.995	5.114	0.209	1.42
ASAE	QWT	3195.58	2535.967	0.243	1.472
	ICYMSP	1.193	5.013	0.818	1.472

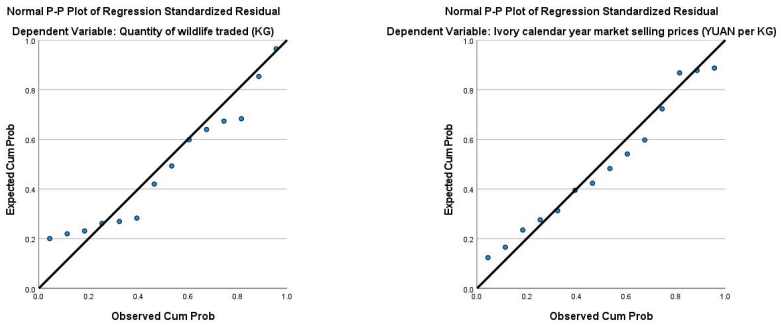

Figure 4. QWT(Left) and ICYMSP(Right)'s P-P Diagram

The P-P diagram corresponding to QWT and ICYMSP is as follows:

From Table 4, we can get the linear regression equation calculation formula below:

$$QWT = -0.700B + 18162.481NCC + 43578.243NAL - 1520.511PPD + 3195.590ASAE - 1016036.182 \quad (7)$$

$$ICYMSP = -0.001B + 27.25NCC + 66.35NAL - 6.995PPD + 1.193ASAE + 3611.821 \quad (8)$$

Linear regression models have some limitations. For instance, predictions can be inaccurate when the significant value of some factors and dependent is greater than 0.05. We also use the ARIMA model as a supplement to overcome this issue.

3.2.2 ARIMA Time Series Model

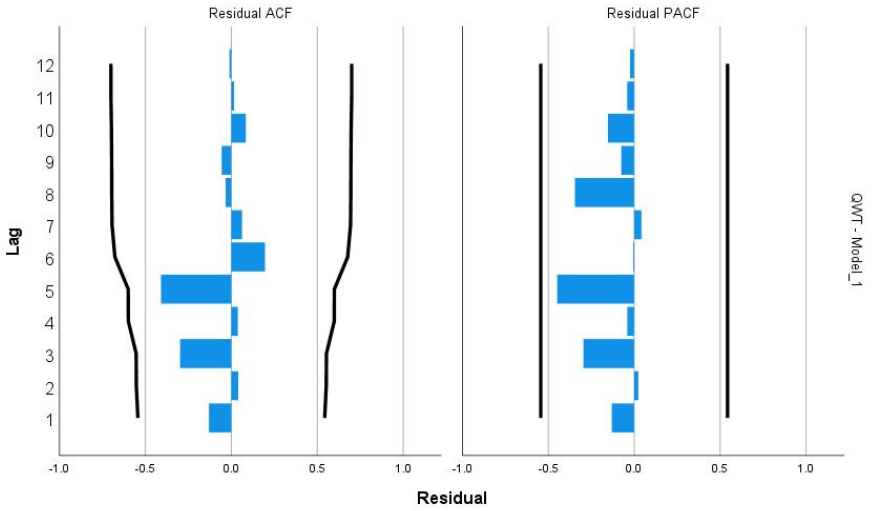

Figure 5. ACF and PACF of QWT

We used a statistical model called ARIMA (p,d,q) to analyze the time series data of two dependent variables, QWT and ICYMSP. ARIMA combines three models - autoregressive (AR), moving average (MA), and difference method. Our analysis has yielded the following results:

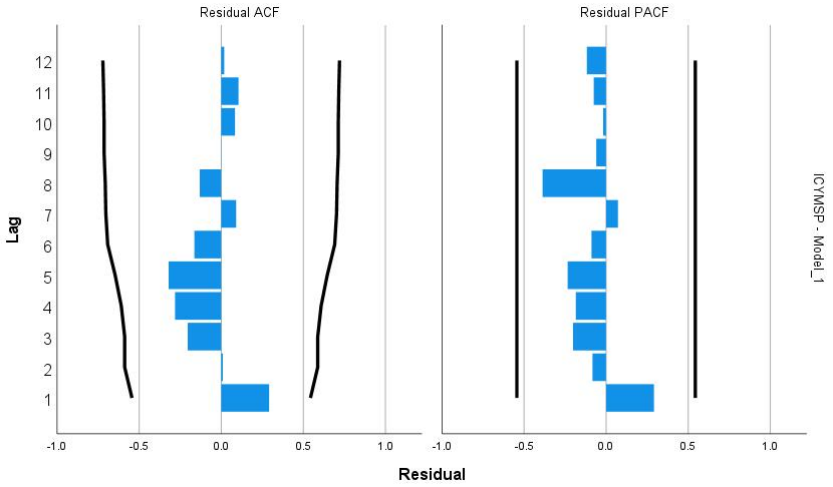

Figure 6. ACF and PACF of ICYMSP

Based on the ACF and PACF diagrams, we can observe that whether we use QWT or ICYMSP as the dependent variable, the ARIMA model's three parameters are p = q = 0 and d = 1, respectively.

The following figures depict the results of fitting the ARIMA time series to QWT and ICTMSP as the dependent variables. The fitted curve closely resembles the actual curve, indicating an excellent fitting effect.

3.3.1 Intervention Analysis

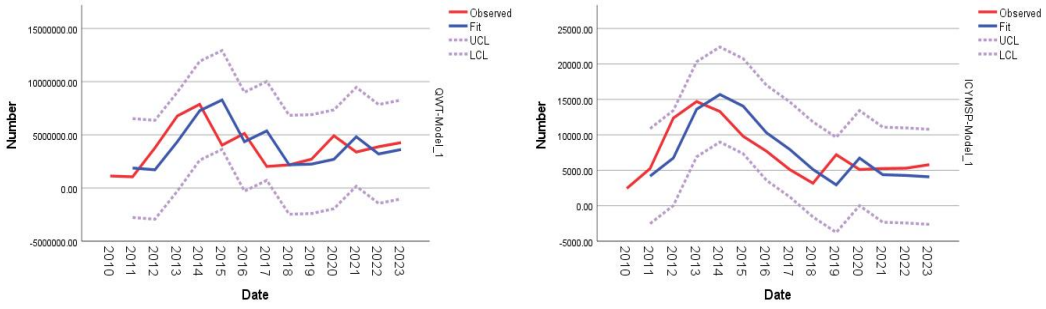

Figure 7. ARIMA Model's Fitting Result

Based on the existing data, we use the ARIMA model to predict and analyze the trends of QWT and ICYMSP in the next three years (2024, 2025, 2026) without intervention.

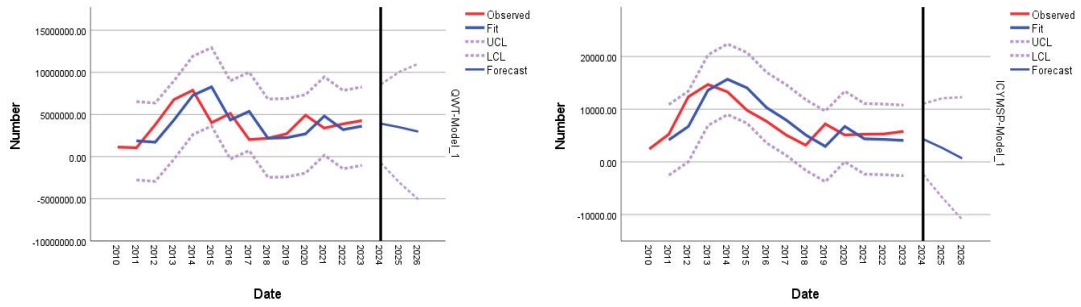

Figure 8. ARIMA Model's Predicting Result

The prediction results indicate that QWT and ICYMSP are decreasing without intervention. We expect that our intervention would hasten the decline of QWT and slow the decrease of ICYMSP or even directly increase it.

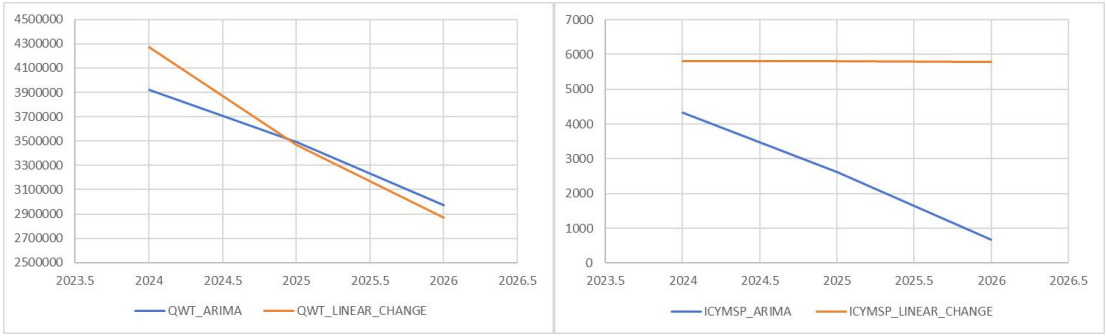

Figure 9. Comparison of Intervention Results

After thorough analysis and discussion, we utilized the linear regression model that we established previously to predict the next three years' data, ensuring objectivity and accuracy of the forecast to the fullest extent possible. We assume that all four dependent variables will increase by 5% following the execution of our project. With this intervention, we can expect the following results (Figure 9).

The blue line is the predicted trend using the ARIMA model above, while the orange line is the expected trend after intervention using the linear regression model. It can be seen that after the intervention, QWT decreased rapidly, while ICYMSP remained high. This is precisely what we expect - a reduction in trade volume is needless to say, and if prices remain high, fewer people will buy.

4. Sensitivity analysis

We analyzed relevant data and selected NCC and ASAE, the two indicators most susceptible to uncontrollable factors, for analysis. Due to space limitations, we cannot present the complete data set (Argyrous, 2011).

Table 6. Datasets

Year	NCC	ASAE	CI	GDP	TISD	TI	PGDG	T
2010	34	256	35	6087.19	133.38	5.03	33.9	7.56
2011	27	381	36	7551.52	116.44	5.11	33.8	7.37
2012	45	426	39	8532.19	117.91	5.02	34.4	7.06
				...				

We opted to utilize the stepwise regression method for performing sensitivity analysis. This method enables the system to identify influential variables automatically. The influential variables are included in the regression model if the model is statistically significant. Additionally, we eliminate variables that are not statistically significant.

4.1 Sensitivity Analysis for NCC

After applying the stepwise regression method, we identified several factors that significantly affect NCC. The analysis revealed that the sensitivity coefficient of GDP to NCC is 0.025, the sensitivity coefficient of PGDG to NCC is -6.471, and the sensitivity coefficient of temperature to NCC is 112.859. These values are presented below:

Table 7. Sensitivity Analysis for NCC

	B	SE	Sig.	LB	UB
Constant	-754.031	217.739	0.009	-1256.14	-251.925
GDP	0.025	0.006	0.004	0.011	0.04
PGDP	-6.471	1.486	0.002	-9.898	-3.043
T	112.859	31.247	0.007	40.804	184.914

Considering actual conditions and sensitivity coefficient considerations, it can be concluded that temperature and PGDG may be two uncontrollable factors that have a more significant impact.

4.2 Sensitivity Analysis for ASAE

The factor that has a significant impact on ASAE is PGDG. The sensitivity coefficient of PGDG to ASAE is 10.724, as shown in the following table (Figure 8):

Considering the actual situation and sensitivity coefficient, PGDG may be an uncontrollable factor with a more significant impact.

Table 8. Sensitivity Analysis for ASAE

	B	SE	Sig.	LB	UB
Constant	14.874	308.461	0.962	-672.42	702.168
PGDG	10.724	6.099	0.109	-2.866	24.313

5. Conclusion

Based on ARIMA predictions and intervention analyses, we demonstrate the effectiveness of the following initiatives undertaken by China's wildlife conservation agencies:

1. Enhance legal measures, enforcement policies, and supply chain controls.
2. Decrease the demand for illegal wildlife products.
3. Strengthen international collaboration and coordination.
4. Develop a robust monitoring and evaluation system to evaluate the progress and impact of the project.

From the above analysis, we can learn that since the illegal wildlife trade was rampant around 2010, China’s wildlife protection agencies have gradually introduced relevant measures and rewards and punishments in this field. To a certain extent, the crime of illegal wildlife trade has been better curdled. However, we can also find that although the overall trend of the Chinese government can reduce illicit trade behavior, the short-term trend is not stable, and it is likely that the emergence of new wildlife products will trigger a new round of smuggling waves. China’s wildlife protection agencies can continue to increase law enforcement efforts on this issue, and their most significant responsibility is to reduce the occurrence of illegal wildlife trade practices.

By utilizing linear regression models, multiple regression models, ARIMA models, entropy weight methods, and situational sensitivity analysis methods, we are able to consider more factors comprehensively at both the macro and micro levels. This simplifies the research complexity and enables us to model data performance based on the correlation between various influencing factors. We focus on the most influential factors to achieve better results.

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