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DRIVING FACTORS BEHIND IMPORTED FOOD DETENTION RISKS AND HETEROGENEOUS FEATURES BASED ON MULTI-SOURCE CUSTOMS TRADE RECORDS

Yi Wang
School of Government, University of International Business and Economics, Beijing 100029, China.

Abstract: Against the backdrop of expanding cross-border food trade and constrained inspection resources, identifying risk signals from massive customs records has become a core task for intelligent border supervision. This study constructs unbalanced panel data covering HS8 products, trade partners and monthly records using multi-source trade and detention data, and adopts PPML-HDFE estimation to separately examine driving factors for two categories of detention risks: procedural compliance failures and intrinsic safety defects. Empirical outcomes show obvious heterogeneity in influencing factors between the two risk types. Past detention records serve as the most stable risk indicator, with stronger persistence for safety-related violations. Abnormally low prices display a consistent positive correlation with procedural non-compliance yet offer limited explanatory power for safety risks. Cumulative long-term import volume mitigates detention probabilities, reflecting risk reduction brought by mature supply chains. The above conclusions remain robust after multiple robustness checks and endogenous bias treatments, and differ across food categories and economic levels of exporting economies. This research delivers quantitative evidence for classified risk warning and optimized allocation of inspection resources under intelligent customs frameworks.
Keywords: Imported food safety; Detention risk; PPML-HDFE; Intelligent border supervision; Cross-border food trade

1 INTRODUCTION

The continuous expansion of cross-border food trade has enriched consumer choices while extending global supply chains across multiple production, transit and inspection nodes. As border inspection volumes surge year by year, supervision authorities face a prominent contradiction between soaring inspection demands and constrained manpower and equipment resources [1,2]. Massive historical trade archives and detention notices accumulate on intelligent supervision platforms, yet most raw data remain underutilized without interpretable quantitative risk indicators [3,4]. Official statistical records show a steady rise in cross-border food detention incidents, which indicates compound risks intertwined with production standards, document administration and cross-border circulation rules [5]. Modern digital border governance initiatives propose data-driven risk screening, which raises urgent demands to identify stable, verifiable warning signals from multi-source trade datasets for targeted inspection scheduling.

Two dominant research branches exist within the field of cross-border food risk governance. The first branch focuses on institutional supervision frameworks, elaborating theoretical logics of risk assessment, communication and whole-chain monitoring, but mostly stays at qualitative discussion without quantitative validation of actionable risk predictors [6]. The second branch adopts statistical and data mining tools to measure hazard probabilities, including Logistic regression, Bayesian inference and risk matrix methods [7,8]. Nevertheless, most prior empirical works rely on partial regional samples or single-type inspection data, and seldom differentiate procedural detention failures from intrinsic safety defects, ignoring their distinct formation mechanisms [9]. In addition, few scholars adopt high-dimensional fixed-effects Poisson models tailored to zero-inflated detention count data, while failing to control unobserved time-varying cross-border shocks and fixed product-origin traits in estimation [10]. Empirical evidence comparing heterogeneous driving forces of two detention categories on comprehensive multi-source panel data is still insufficient in existing literature.

This paper delivers three distinct marginal contributions compared with prior separated single-risk and single-data analyses. First, integrated multi-source unbalanced panel data covering monthly, HS8 product and trade partner dimensions are constructed, which systematically distinguishes procedural compliance detention events and intrinsic safety detention events as separate explained variables. Second, the PPML-HDFE model is introduced to fit the sparse, zero-concentrated distribution of detention records, simultaneously absorbing multiple layers of fixed effects to alleviate omitted variable bias and produce unbiased heterogeneous coefficient estimates. Third, a series of robustness checks, endogenous lag treatments and subgroup heterogeneity tests are carried out. The quantified differentiated risk signals provide solid empirical support for classified early warning systems and efficient supervision resource allocation under intelligent border management frameworks.

2 METHODOLOGY

2.1 Model Specification

To accurately identify the driving factors of two categories of import detention incidents (procedural compliance violations and substantive safety hazards), this study follows the estimation framework and adopts the Poisson Pseudo-Maximum Likelihood (PPML) method to construct a high-dimensional fixed effects model specified as Equation (1):

$$E(Y_{hct}^{k} \mid X)=exp\left[\begin{matrix}\beta_1 LowGap_{hct}+\beta_2 HighGap_{hct}+\beta_3 lnHistRisk_{hct}^{k}+\beta_4 HHI_{ht}+\beta_5 HHI_{ht}^{2} \\ +\beta_6 GenShare_{hct}+\beta_7 lnHistImport_{hct}+\alpha_{hc}+\delta_{ct}\end{matrix}\right] \quad (1)$$

Where Y_{hct}^{k} denotes the count of category-k detention incidents of HS 8-digit product h imported from country c in period t. The subscript k separately represents procedural compliance detention and substantive safety detention. $LowGap_{hct}$ and $HighGap_{hct}$ refer to negative low-price deviation and positive high-price deviation, respectively; $HistRisk_{hct}^{k}$ measures historical detention risk of the corresponding category; HHI_{ht} and its quadratic term capture import source concentration and its nonlinear impact; $GenShare_{hct}$ stands for the share of general trade volume; $lnHistImport_{hct}$ represents historical import scale. α_{hc} and δ_{ct} denote product-by-origin fixed effects and origin-by-month fixed effects, which absorb time-invariant traits of each product-origin pair and common time-varying shocks hitting one origin country in a specific month. Meanwhile, the log value of current import volume $lnImport_{hct}$ is set as an offset term with its coefficient restricted to 1, eliminating bias brought by heterogeneous exposure scales across different trade combinations.

2.2 Variable Construction, Data Sources and Descriptive Statistics

2.2.1 Explained variable: count of detention incidents

The explained variable is the total count of import food detention incidents, further divided into two mutually exclusive categories: procedural compliance violations and substantive safety hazards.

Procedural detention incidents mainly stem from irregular labeling, incomplete certification materials, unqualified access qualification, non-compliant packaging and inconsistent documentary paperwork.

Substantive safety detention incidents cover microbial contamination, veterinary drug residues, heavy metal excess, illegal additives, pollutants, sensory defects and other hazards that directly threaten food safety.

This study builds keyword dictionaries based on official detention document descriptions issued by customs food safety authorities. Since a single batch may trigger multiple non-compliance causes, multi-label classification combined with manual recheck is adopted to quantify detention counts.

2.2.2 Explanatory and control variables

Core explanatory variables fall into four groups: Historical risk indicator $lnHistRisk_{hct}^{k}$: cumulative detention records of the corresponding category for each product-origin pair in the past 3 months.

Price signal factors $LowGap_{hct}$ and $HighGap_{hct}$: taking the median import price of the same product in the identical period as the benchmark, the log deviation of actual transaction prices relative to the benchmark price is decomposed into non-negative low-price signals and non-negative high-price signals.

Historical import scale $lnHistImport_{hct}$: measured by the total import volume of the past 3 months. Import source concentration: centered HHI and its quadratic term. Control variables mainly include trade structure indicators such as general trade volume share. The fixed effect structure undertakes the function of absorbing confounding variables: product-origin fixed effects eliminate persistent heterogeneity across product-origin groups; origin-month fixed effects absorb common shocks faced by one source country in a specific time window. Descriptive statistics of all core variables are presented in Table 1.

Table 1 Descriptive Statistics of Main Variables

Variable Name	Variable Definition	Mean	SD	Min	Max	Observations
Procedural	Count of procedural detention incidents	0.028	0.538	0	97	360,890
Safety	Count of substantive safety detention incidents	0.026	0.685	0	151	360,890
Low_price	Non-negative low-price gap	0.204	0.398	0	5.222	354,249
High_price	Non-negative high-price gap	0.297	0.590	0	10.812	354,249
Hist_proc3	3-month historical procedural risk	0.029	0.205	0	4.883	346,663
Hist_safety3	3-month historical safety risk	0.023	0.186	0	5.673	346,663
Ln_histimport	Logarithm of historical import volume	10.804	4.865	0	23.586	346,663
Lnimport	Offset term: log of current import value	10.617	3.458	-0.693	22.630	360,890
Genshare	General trade volume share	7.862	3.671	0	10	360,890
Hhi	Centered HHI	0	0.256	-0.352	0.591	360,890
Hhi_2	Quadratic term of HHI	0.065	0.089	0	0.349	360,890

Price signals, historical import scale and trade structure indicators are extracted from the full-port customs trade database to characterize import exposure scale and trade composition features. Detention-related information originates from official food safety detention documents released by customs authorities, which reflect risk signals captured and

penalized during port supervision. All variables are self-calculated by the author. The sample panel covers monthly-product-origin observations spanning January 2019 to December 2025.

Table 1 demonstrates that detention incidents feature low frequency and sparsity, with severe zero inflation and over-dispersion in distribution. Price-related variables show obvious right skewness, and most trade flow observations hover around median levels. The standard deviation of HHI reaches 0.26, implying substantial divergence in import source structure across products and months. Historical risk variables are also highly sparse; only a small subset of product-origin pairs with prior detention records carry intensive risk information. Overall, the dataset simultaneously satisfies low-frequency count, zero-inflated and high-heterogeneity properties, making the PPML-HDFE model highly applicable for this empirical context.

3 RESULTS

3.1 Baseline Regression

Baseline regression results for procedural and substantive safety detention risks are listed in Table 2. Two separate regressions take procedural detention count and substantive safety detention count as explained variables respectively, both incorporating two-way fixed effects (product-origin and origin-month) and adopting the log of current import value as the offset term.

Table 2 Baseline Regression Results

Variable	Procedural	Safety
Ln_husd3_plus1	-0.128* (0.027)	-0.117* (0.036)
Hist_risk	0.286* (0.053)	0.653* (0.097)
Low_price	0.489* (0.140)	-0.128 (0.190)
High_price	-0.238 (0.187)	0.161 (0.242)
Hhi	-0.849* (0.512)	0.022 (0.468)
Hhi_2	3.230* (1.884)	-3.093\\ (1.401)
Gen_share	0.020 (0.027)	0.002 (0.029)
Pseudo R2	0.390	0.444
HDFE	Yes	Yes
N	38,449	29,609

Notes: Clustered robust standard errors (clustered at product-origin and origin-month levels) are reported in parentheses; * p<0.01, \\ p<0.05, * p<0.1. hist_risk refers to 3-month historical risk of the corresponding detention category.

Regression outcomes indicate that historical risk carries significantly positive coefficients at the 1% significance level in both models (0.286 for procedural violations, 0.653 for safety hazards). Product-origin pairs with prior detention records face higher probability of non-compliance incidents in the current period, proving historical detention archives deliver valid risk identification signals. The larger coefficient magnitude of the safety group implies stronger persistence of substantive safety risks, which can be attributed to structural gaps in production systems, processing workflows and supply chain quality control (distinguished from short-term procedural defects).

Moreover, price signals present prominent heterogeneous effects across two risk categories. The low-price indicator is significantly positive at the 1% level in the procedural model yet insignificant for safety hazards. This reveals abnormal low transaction prices correlate stably with labeling irregularities, documentary defects and registration violations, but fail to predict intrinsic food safety hazards reliably. High-price deviation yields insignificant coefficients in both models, suggesting upward price bias lacks robust explanatory power for either detention type.

Historical import scale holds significantly negative coefficients at the 1% level across both regressions. After controlling current exposure volume, fixed effects and other confounding factors, product-origin pairs with larger long-term import volume experience lower detention probability, which reflects risk mitigation brought by mature supply chains and stable trade partnerships.

HHI demonstrates divergent nonlinear patterns for two risk categories: a significant U-shaped relationship emerges for procedural violations, while a significant inverted U-shaped curve applies to safety hazards. This verifies heterogeneous mechanisms through which import source concentration shapes two types of detention risks. This study only discusses potential influencing channels without further exploring intrinsic micro-mechanisms.

In summary, procedural and substantive safety detention risks differ drastically in driving factor composition. Historical risk generates stable predictive power for both hazards, yet exhibits stronger persistence for substantive safety issues. Low-price signals only deliver consistent predictive value for procedural non-compliance. Regression results preliminarily validate that historical risk, price deviation and historical import scale serve as core indicators to distinguish two detention categories

3.2 Robustness Tests

3.2.1 Alternative historical time windows

To verify whether baseline conclusions rely on the 3-month historical risk window, this study replaces the 3-month historical risk variable with 6-month and 12-month counterparts and re-estimates the baseline model. Regression outputs are shown in Table 3.

Table 3 Robustness Test: Alternative Historical Windows

Variable	M6_Procedural	M6_Safety	M12_Procedural	M12_Safety
Hist_risk	0.198* (0.051)	0.452* (0.117)	0.051 (0.058)	0.260* (0.139)
Ln_hist_import	-0.138* (0.033)	-0.079* (0.038)	-0.120* (0.038)	-0.082* (0.048)
Low_price	0.490* (0.139)	-0.134 (0.195)	0.503* (0.142)	-0.116 (0.201)
High_price	-0.255 (0.191)	0.115 (0.244)	-0.241 (0.197)	0.071 (0.257)
Hhi	-0.824 (0.523)	0.142 (0.588)	-0.846 (0.555)	0.328 (0.860)
Hhi_2	3.313* (1.855)	-3.284\\ (1.482)	3.291* (1.896)	-3.400\\ (1.676)
N	38,449	29,609	38,449	29,609
Pseudo R2	0.386	0.431	0.383	0.420

Regression results show historical risk remains significantly positive for both detention categories under the 6-month window. When extended to a 12-month horizon, historical risk retains significance solely for substantive safety hazards and loses statistical power for procedural violations. This confirms historical risk carries time-decaying features, with faster attenuation for procedural non-compliance. The distinction originates from the fact that procedural irregularities can be rectified within short cycles, while adjustments to production technology and quality management systems (root causes of safety hazards) require longer lead times.

Coefficients of price signals and historical import scale remain consistent with baseline estimates under all window settings, proving the risk identification value embedded in these indicators is robust and further validates divergent factor structures across two detention types.

3.2.2 Stricter fixed effects specification

Different HS chapters of food products may face synchronized monthly shocks such as seasonal import volatility, industry-wide regulatory adjustments, global price swings and category-specific risk incidents. To mitigate omitted variable bias arising from this channel, HS chapter-by-month fixed effects are added to the baseline model. Regression results are displayed in Table 4.

After absorbing monthly common shocks at the HS chapter level, historical risk remains significantly positive at the 1% level for both detention categories. Low-price signals retain significant positive correlation with procedural violations but stay insignificant for safety hazards. Historical import scale maintains significantly negative coefficients in the procedural group. All core conclusions experience no substantive changes, confirming baseline findings are not driven by synchronized monthly shocks specific to individual product chapters.

Table 4 Robustness Test: Stricter Fixed Effects & Alternative Exposure Offset

Variable	**HS2_Procedural**	**HS2_Safety**	**ln(qty)_Procedural**	**ln(qty)_Safety**
Hist_risk	0.245* (0.047)	0.388* (0.078)	0.281* (0.054)	0.618* (0.093)
Ln_hist_import	-0.109* (0.030)	-0.061 (0.041)	-0.133* (0.031)	-0.119* (0.038)
Low_price	0.586* (0.143)	-0.083 (0.188)	-0.121 (0.196)	-0.734* (0.219)
High_price	-0.270 (0.176)	-0.016 (0.193)	0.572* (0.205)	0.947* (0.249)
Hhi			-0.217 (0.507)	0.670 (0.595)
Hhi_2	2.735 (1.696)	-3.557\\ (1.531)		
Gen_share			0.025 (0.026)	0.027 (0.030)
Pseudo R2	0.455	0.523	0.455	0.523
Baseline FE	Yes	Yes	Yes	Yes
Origin×Month FE	Yes	Yes	Yes	Yes
N	33,557	25,326	38,449	29,609

3.2.3 Alternative risk exposure measurement

Import value may be distorted by price fluctuations, so this study replaces the log of import value with the log of import weight (kilograms) as the offset term and re-runs the baseline regression, with outputs listed in Table 4 above.

Core coefficients of historical risk and historical import scale remain stable, while price signal magnitudes shift noticeably: the low-price indicator loses significance in the procedural model and turns significantly negative for safety hazards. A plausible explanation lies in the intrinsic correlation between price signals and value-based offset terms:

import value equals unit price multiplied by physical quantity. Substituting value with volume breaks the statistical linkage between price variables and the offset term, triggering coefficient fluctuations.
This contrast indirectly proves the risk identification function of price signals operates primarily through the trade value channel. Given port risk sorting practices generally rely on import value thresholds, adopting value as the exposure offset delivers stronger policy relevance for supervision authorities.

3.3 Endogeneity Treatment

Although high-dimensional fixed effects absorb time-invariant product-origin traits and origin-wide time-varying shocks, reverse causality bias may persist between price, trade structure variables and detention risks. For instance, market participants may anticipate latent risks and adjust import prices in advance; unobserved short-term shocks simultaneously distort pricing, trade volume and supervision stringency; past detention incidents may feed back into subsequent import scale and trade composition.
To mitigate such endogenous distortions, all explanatory variables (price signals, HHI and historical import scale) are lagged by one period to sever contemporaneous reverse causal links, while retaining same-category historical risk variables. Revised regression results are reported in Table 5.

Table 5 Endogeneity Test: One-Period Lagged Explanatory Variables

Variable	Procedural	Safety
Hist_risk	0.284* (0.049)	0.655* (0.100)
L1_ln_hist_import	-0.106\\ (0.042)	-0.102* (0.037)
L1_low_price	0.465\\ (0.196)	0.017 (0.155)
L1_high_price	0.328 (0.231)	0.144 (0.211)
L1_hhi	-0.846* (0.472)	0.299 (0.459)
L1_hhi_2	3.332\\ (1.327)	-0.910 (1.124)
L1_gen_share	-0.015 (0.029)	-0.014 (0.022)
Pseudo R2	0.395	0.428
HDFE	Yes	Yes
N	35,563	27,655

After lagging all explanatory variables by one period, historical risk remains significantly positive at the 1% level in both models, consistent with baseline regression. Sign and significance of lagged price signals, historical import scale and HHI align closely with original estimates. This validates core empirical findings are not driven by contemporaneous bias between pricing and detention incidents; historical risk, low-price gap and historical import scale maintain independent robust predictive power.

3.4 Heterogeneity Analysis

3.4.1 Heterogeneity by product category

TTo test heterogeneous applicability of risk predictors across food types, all imported food products are classified into five groups based on HS chapter attributes: animal-derived primary food, plant-derived primary food, oil-sugar-formula food, processed food, and beverage-alcohol products. Grouped regression outputs are presented in Table 6 and Table 7.

Table 6 Heterogeneity Analysis: Procedural Risk by Product Category

Variable	Animal	Plant	Oils	Processed	Beverages
hist_risk	0.372* (0.076)	0.416 (0.366)	-0.568* (0.340)	0.153 (0.096)	0.188\\ (0.083)
ln_hist_import	-0.064 (0.043)	-0.201* (0.104)	-0.277 (2.833)	-0.192* (0.066)	-0.011 (0.092)
low_price	0.511 (0.341)	0.363 (0.730)	-0.271 (0.886)	0.421 (0.318)	0.097 (0.424)
high_price	-0.813* (0.472)	-0.582 (0.698)	-0.081 (0.502)	-0.130 (0.279)	-0.566 (0.522)
hhi	1.552* (0.811)	-1.164 (1.899)	-2.622\\ (1.287)	-1.765* (0.672)	-0.471 (1.154)
hhi_2	4.120* (2.336)	2.700 (4.163)	2.102 (2.833)	1.378 (2.538)	2.332 (2.430)
Controls&HDFE	Yes	Yes	Yes	Yes	Yes
N	7,334	672	1,194	9,987	2,046

Table 7 Heterogeneity Analysis: Substantive Safety Risk by Product Category

Variable	Animal	Plant	Oils	Processed	Beverages
Hist_risk	0.383* (0.182)	0.937* (0.187)	-0.169 (0.282)	0.412* (0.085)	0.402\\ (0.190)

Ln_hist_import	-0.004 (0.101)	0.157 (0.125)	-0.293\\ (0.142)	0.020 (0.077)	-0.370\\ (0.147)
Low_price	0.664 (0.618)	-0.418 (0.452)	0.910\\ (0.457)	-0.261 (0.243)	-0.480 (0.667)
High_price	-0.873* (0.415)	0.363 (0.612)	1.629* (0.620)	-0.388 (0.247)	-0.295 (0.519)
Hhi	3.967* (0.914)	-1.713 (1.042)	0.175 (1.903)	-1.183* (0.414)	2.013 (2.101)
Hhi_2	-9.961* (2.990)	5.818\\ (2.641)	1.756 (3.310)	-1.264 (2.119)	0.947 (5.345)
Controls&HDFE	Yes	Yes	Yes	Yes	Yes
N	3,298	1,261	673	9,387	1,012

Regression results show historical risk holds significantly positive coefficients across most product subgroups, with stronger cross-category robustness for substantive safety hazards: significant positive effects emerge in animal-derived, plant-derived, processed food and beverage-alcohol subsamples. This further confirms historical detention records represent the most stable and universally applicable indicator for import food risk identification.

Although reduced observation counts within split subgroups render some coefficients statistically insignificant, the asymmetric relationship of low-price signals across two risk categories remains identifiable in most subsamples. The baseline conclusion that low-price indicators primarily predict procedural violations while delivering limited explanatory power for safety hazards holds across product subgroups, with significance fluctuations driven solely by shrinking sample size after grouping.

3.4.2 Heterogeneity by origin country development level

Following IMF classification standards, source economies are split into advanced economies and developing economies to explore heterogeneous factor impacts under divergent institutional environments and trade structures. Grouped regression results are displayed in Table 8.

Table 8 Heterogeneity Analysis by Origin Economic Development Level

Variable	Procedure_ed	Procedure_ing	Safety_ed	Safety_ing
Hist_risk	0.255* (0.055)	0.357* (0.110)	0.711* (0.091)	0.416* (0.091)
Ln_hist_import	-0.208* (0.050)	-0.073\\ (0.037)	-0.226* (0.066)	-0.014 (0.041)
Low_price	0.514* (0.161)	0.514* (0.273)	-0.164 (0.224)	0.089 (0.363)
High_price	-0.263 (0.219)	-0.078 (0.328)	0.240 (0.314)	0.179 (0.359)
Hhi	-0.634 (0.517)	-1.053 (0.828)	1.728* (0.651)	-1.466* (0.502)
Hhi_2	2.511 (1.758)	4.213 (3.130)	-1.202 (2.145)	-2.579* (1.442)
Controls	Yes	Yes	Yes	Yes
HS8×Origin FE	Yes	Yes	Yes	Yes
Origin×Month FE	Yes	Yes	Yes	Yes
N	17,216	21,233	15,644	13,965

Regression outputs demonstrate historical risk remains significantly positive at the 1% level across four subgroups, further verifying cross-origin robustness of historical detention records as risk identification signals. Prior detention incidents deliver valid predictive information for current hazards regardless of whether the source economy is advanced or developing.

The asymmetric effect of low-price signals reappears in this heterogeneity test: low-price indicators hold significant positive coefficients for procedural violations in both advanced and developing origin groups, yet remain insignificant for safety hazards in both subgroups. This reinforces that low-price deviations primarily reflect gaps in compliance investment, labeling documentation and registration formalities, rather than intrinsic food safety defects.

The risk-mitigating effect of historical import scale displays prominent origin heterogeneity. The indicator holds significantly negative coefficients at the 1% level for both risk categories in advanced origin groups, while only significantly suppresses procedural violations (with no meaningful impact on safety hazards) for developing economies. This implies risk reduction embedded in mature supply chains and stable trade partnerships partially relies on institutional governance capacity and supply chain management maturity of source economies.

4 CONCLUSIONS

This paper constructs multi-dimensional unbalanced panel data covering product-origin-month dimensions and adopts the PPML-HDFE high-dimensional fixed effect model to systematically compare the heterogeneous driving forces of procedural and substantive detention risks of imported food. A full set of robustness tests, endogenous lag processing and grouped heterogeneity analyses are carried out to verify the reliability of empirical findings. The overall estimation results reveal that historical detention records act as the most persistent and universal risk warning indicator, and substantive safety risks show longer time persistence than procedural irregularities. Abnormal low price gaps only effectively predict procedural non-compliance issues without predictive value for intrinsic food safety hazards. Long-term stable import scale can significantly reduce detention probability, and import source concentration presents

differentiated nonlinear effects on two risk types. The indicator system and quantitative identification logic proposed in this paper possess outstanding practical operability for intelligent border supervision. All core variables can be extracted from existing customs trade and supervision archives without extra costly data collection, and the differentiated risk threshold standards derived from regression coefficients can be directly embedded into automated risk screening systems to realize classified inspection allocation, ease the pressure of limited supervision manpower and equipment, and improve the hit rate of hidden risks in daily port supervision.

This research leaves multiple expandable directions for subsequent academic exploration and practical optimization. In theoretical extension, follow-up research can further excavate the mediating and moderating transmission paths between trade characteristics and detention risks, and clarify the micro supply chain mechanisms behind the time decay difference of two risk types. In data and model optimization, more supervision indicators such as exporter qualification and logistics records can be incorporated to build a multi-layer comprehensive risk assessment framework. In practical application, targeted risk intervention policies can be designed according to subgroup heterogeneous characteristics: differentiated inspection intensity and pre-entry document review standards can be formulated for different food categories and source economies, forming a whole-chain risk prevention system combining pre-warning, on-site inspection and post-event tracking.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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