Proceedings of Business and Economic Studies, 2026, Volume 9, Issue 8
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on Risk Identification and Audit Governance of Bid Rigging and Collusion in Overseas Procurement Bidding: Joint Analysis Based on SDTM Model and Correlation Coefficient

Mingxuan Hou

CNPC Overseas Audit Center, Beijing 100000, China

Abstract: With the continuous expansion of central SOEs' overseas business scale, overseas procurement bidding activities have formed a more complex and concealed risk structure. Bid rigging and collusion have evolved from traditional explicit collaborative behaviors into complex implicit and structured coordination across multiple entities. Against the backdrop of divergent cross-jurisdictional supervision and information asymmetry, experience-based audit approaches can no longer meet risk identification demands. On the basis of systematically analyzing the formation mechanism of bid rigging, this paper constructs a joint identification framework integrating the SDTM standard deviation model and correlation coefficient model to quantitatively identify bid rigging from two dimensions: quotation dispersion and coordination. The model is verified through a typical overseas information technology project. The research results demonstrate that the model can effectively detect abnormal quotation structures and potential collusive behaviors, providing methodological support for the audit governance of central SOEs' overseas procurement.

Keywords: Bid rigging risk; SDTM model; Correlation coefficient; Audit governance; Overseas procurement

Online publication: August 31, 2026

1. Introduction

In recent years, with the in-depth advancement of the Belt and Road Initiative, central SOEs have seen continuous growth in overseas engineering and information technology projects, and procurement bidding has become a vital link in overseas resource allocation. However, as project scales expand and more participants join, anti-competitive behaviors such as bid rigging and collusion have grown more concealed and complicated. Particularly in cross-border operating environments, significant disparities in national legal systems and insufficient market transparency further exacerbate information asymmetry throughout the bidding process, raising difficulties for audit identification. Against this context, traditional audit methods relying primarily on

experience have revealed obvious limitations. Therefore, data-driven analytical models are urgently needed to strengthen risk identification capabilities [1].

2. Formation mechanism of bid rigging risks

Overseas procurement bidding features numerous participants, lengthy business chains, and complicated regulatory environments. Bid rigging rarely stems from violations by a single entity; instead, it arises as coordinated behavior driven by specific institutional contexts and interest incentives. From an audit practice perspective, the formation of bid rigging risks is affected by three mechanisms: quotation coordination, information asymmetry, and distorted evaluation.

First, regarding the quotation coordination mechanism, the core characteristic of bid rigging is the loss of independent quotation foundations among bidders. Under fully competitive market conditions, enterprises differ in procurement channels, operating costs, management efficiency, and profit expectations, so their quotations generally present scattered distributions. In bid rigging scenarios, relevant parties reach unified pricing strategies through prior communication, resulting in highly consistent quotations or fixed proportional relationships between offers. Such prices are not derived from internal cost calculations and thus display obvious regularities. From an audit perspective, these regularities manifest as large batches of identical quotations or persistent fixed multiples between offers over time.

Second, regarding the information asymmetry mechanism, overseas projects span wide geographic areas with multi-layered management and lengthy information transmission chains. Headquarters management cannot obtain full real-time information about on-site procurement activities, and key data are only aggregated and reported tier by tier by project units. During information transfer, original data may be simplified, omitted, or selectively disclosed, weakening oversight by management and audit departments. For bidders, such regulatory blind spots objectively create room to conduct bid rigging and increase the difficulty of detecting irregularities.

Third, regarding the distorted evaluation mechanism, even complete bid evaluation standards laid out in tender documents may fail to block bid rigging if implementation suffers from lax reviews, missing procedures, or incomplete evaluation records. Especially for overseas projects with insufficient professional staffing in management offices, tender documents are not rigorously verified for authenticity and completeness, allowing unqualified bids to enter subsequent evaluation procedures and ultimately compromising the fairness of bidding outcomes [2].

Accordingly, bid rigging risks are not merely pricing issues but the combined effect of coordinated quotations, information asymmetry, and distorted evaluations. Only by starting from their formation mechanisms can a more effective identification and governance system be established.

3. Joint identification model of SDTM and correlation coefficient

This paper first adopts the SDTM standard deviation model to measure quotation dispersion. Its economic implication is that fuller market competition corresponds to higher price dispersion. Standard deviation essentially measures the fluctuation of sample data around the average. In fully competitive markets, supplier quotations naturally differ, yielding standard deviations within reasonable ranges. When bidders collude, their offers converge, and the standard deviation drops sharply. Standard deviation therefore serves as a core indicator for bid rigging risk detection.

Assume there are n bidders for one tender lot, and the quotation of bidder i for procurement item j is x_{ij}. The average quotation of item j is calculated as:

$$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$$

Where: $\overline{x_j}$: Average quotation of procurement item j;
x_{ij} : Quotation of bidder i for procurement item j;
n: Number of participating bidders.
The standard deviation of quotations for item j is further calculated as:

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{ij} - \overline{x_j}\right)^2}$$

Where:

$\acute{o}_j$: Standard deviation of quotations for procurement item j;
$x_{ij} - \overline{x_j}$: Deviation between individual quotation and average quotation;
$\left(x_{ij} - \overline{x_j}\right)^2$: Squared deviation value.

3.2. Correlation coefficient model

Standard deviation alone has limitations. Some colluding bidders may artificially adjust offers to keep standard deviations within normal thresholds and evade detection. This paper therefore introduces correlation coefficient analysis to characterize synchronized quotation trends between bidders. The correlation coefficient quantifies the consistency of quotation fluctuation directions across parties. If multiple bidders raise or lower prices simultaneously, their correlation coefficient approaches 1; if quotation movements are independent, the coefficient remains low. Correlation coefficients can thus identify hidden collusive patterns behind price structures.

The correlation coefficient between bidder i and bidder k is defined as:

$$\rho_{ik} = \frac{Cov\left(x_i, x_k\right)}{\sigma_i \sigma_k}$$

Where:

ρ_{ik} : Correlation coefficient between bidder i and bidder k;
$Cov(x_i, x_k)$: Covariance of quotation sequences of bidder i and bidder k;
x_i : Full quotation sequence of bidder i;
x_k : Full quotation sequence of bidder k;
σ_i : Standard deviation of bidder i's quotation sequence;
σ_k : Standard deviation of bidder k's quotation sequence.
The correlation coefficient ρ ranges from -1 to 1, with interpretive criteria as follows:

Value Range ρ	Implication
$\rho \approx 1$	Highly positively correlated
$0.8 \le \rho < 1$	Strong correlation
$0.5 \le \rho < 0.8$	Moderate correlation

$0 \le \rho < 0.5$	Weak correlation
$\rho \approx 0$	Essentially uncorrelated
$\rho < 0$	Negative correlation

Persistent correlation coefficients close to 1 between multiple bidders indicate highly consistent quotation trends and potential collusive pricing.

This paper constructs a joint identification framework combining SDTM and correlation coefficients to comprehensively evaluate bid rigging risks by examining both quotation dispersion and coordination. Compared with single-indicator methods, the framework detects abnormally clustered prices as well as concealed collusive modes including fixed-proportion quotations and synchronized fluctuations. SDTM identifies price clustering while correlation coefficients detect coordination; together they capture three types of bid rigging: identical quotations, proportional quotation structures, and synchronized fluctuating quotations. A joint discriminant function R is built for comprehensive quantitative scoring of bid rigging risks:

$$R = \alpha\left(1 - \frac{\sigma}{\sigma_0}\right) + \beta_\rho$$

Where:

R: Comprehensive bid rigging risk score;

σ : Actual measured quotation standard deviation;

σ_0 : Historical standard deviation benchmark of comparable projects;

ρ : Average correlation coefficient among all bidders;

α : Weight of standard deviation indicator;

β : Weight of correlation coefficient indicator;

$\alpha + \beta = 1$.

4. Case analysis

During the audit of one overseas project, the audit team first conducted an overall review of the tendering and procurement process and carried out full-data analysis on all bid quotations. Five bidders participated in this project, with quotation lists covering over 300 categories of equipment and services.

In the preliminary data analysis stage, the audit team imported all quotations of the five firms into the model for horizontal comparison. The results revealed abnormal overlaps between multiple bidders. Company A and Company B submitted identical quotations for more than 200 items, accounting for over 60% of all listed procurement items. Given natural disparities between suppliers in procurement channels, operating costs, and profit margins, the probability of such a high proportion of identical offers is extremely low, drawing focused attention from the audit team. Further analysis of remaining items found numerous fixed-proportion relationships between quotations of A and B. Such regular differences cannot be random and appeared to be adjusted uniformly from a shared pricing baseline.

To validate the judgment, the audit team applied the correlation coefficient model to the quotation sequences of all bidders. Calculations showed the correlation coefficient between Company A and Company B was far above the average level of competitive projects; the coefficient between Company B and Company C also remained high. This proved highly synchronized quotation trends and obvious collusive characteristics

across the three firms.

5. Audit governance paths

Bid rigging and collusion feature strong concealment, high identification difficulty, and wide-ranging impacts. Reliance solely on ex-post audits cannot deliver effective governance. Combined with case findings and overseas procurement management practices, this paper proposes a trinity governance system of "data identification, process control, and oversight closed-loop" to shift risk governance from ex-post rectification to pre-emptive prevention and full-process control [4,5].

5.1. Building a model-driven data identification system to improve early warning capacity for bid rigging risks

First, establish an overseas procurement bidding database. Classify and aggregate historical procurement data by industry, project type, procurement mode, and host country, gradually building a foundational database covering equipment procurement, engineering construction, and information technology projects. Accumulated historical samples provide data support for threshold setting and model calibration of standard deviations.

Second, construct a bid rigging risk indicator library. Beyond standard deviation and correlation coefficient, introduce metrics such as quotation overlap rate, fixed quotation ratios, and supplier relevance to form a multi-dimensional risk evaluation system. The system automatically triggers alerts and flags projects exceeding predefined risk thresholds as key audit targets.

Third, advance the construction of audit analysis platforms. Leverage big data analytical tools to realize automatic cross-checking of quotations, intelligent recognition of related parties, and automatic screening of abnormal conduct. Embedding the model within procurement management systems enables real-time monitoring and dynamic early warning of bid rigging risks.

5.2. Strengthening full-process procurement control to reduce opportunities for bid rigging

At the procurement demand formulation stage, reinforce rationality reviews of technical specifications. Focus on biased parameter settings, designated brands, and exclusive clauses that artificially narrow competitive scope.

At tender document drafting, implement standardized template management for qualification requirements, scoring criteria, and bid invalidation rules to reduce discretionary human operation space. Quantify bid evaluation standards to improve evaluation transparency and consistency.

At the bidding submission stage, fully deploy electronic bidding platforms. Adopt electronic signatures, timestamp authentication, and online submission to enhance the authenticity and traceability of tender documents. Strictly enforce bid invalidation rules for parties failing to submit required original or electronically signed materials.

At bid evaluation, enforce full-process traceability recording. Automatically log expert scoring, opinion revisions, and result confirmation to form complete electronic audit trails, effectively mitigating risks of human interference in evaluation outcomes.

5.3. Establishing a supplier portrait system for dynamic risk management

Supplier management forms the foundation of overseas procurement risk governance. A full-lifecycle supplier

portrait system should be built to continuously track and dynamically evaluate historical supplier conduct.

On one hand, develop a basic supplier information database including corporate registration, equity structure, core management personnel, and historical project records. On the other hand, build a risk behavior archive recording bid rigging, collusion, false bidding, and performance breaches to form supplier credit files. Historical bidding data can be further analyzed to map supplier portraits covering quotation patterns, bidding frequency, winning ratios, and cooperation networks, identifying hidden collusive groups and abnormal partnerships. Suppliers with high risk ratings shall face stricter access requirements and higher audit sampling frequencies to realize categorized and targeted oversight.

5.4. Advancing forward-shifted audit supervision and building collaborative governance mechanisms

Traditional audits conducted post-project suffer from delayed problem detection and high rectification costs. Tailored to overseas procurement operations, oversight shall shift forward to integrate pre-warning, in-process control, and ex-post assessment.

First, institute an audit intervention mechanism for major projects. Audit departments shall participate in reviews of procurement schemes and tender documents in advance for large-investment, high-risk, or first-entry new-market projects.

Second, establish cross-functional coordination among procurement, legal, discipline inspection, and audit departments. Information sharing and joint oversight will strengthen bid-rigging risk detection capabilities.

Third, build an overseas cross-project risk linkage mechanism. Horizontally compare bidding behaviors of the same supplier across different countries and projects to identify cross-project collusive networks.

Fourth, explore the application of artificial intelligence in procurement audits. Train machine learning algorithms on historical cases to enable automatic identification and intelligent early warning of bid rigging.

6. Conclusion

Bid rigging and collusion risks in overseas procurement display prominent structural and concealed characteristics, arising from the superposition of information asymmetry, coordinated quotation behaviors, and distorted evaluation mechanisms. The joint SDTM and correlation coefficient model constructed in this paper transforms bid rigging detection from experience-based judgment to data-driven quantification. The research verifies that the model possesses strong explanatory power and practical operability, offering valuable references for the audit governance of central SOEs' overseas procurement.

Disclosure statement

The author declares no conflict of interest.

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