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Article

Fighting for collusive bidding in the construction industry: A text mining-enabled approach

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Abstract: Policy measures are crucial for regulating collusive bidding and are integral to effective governance. However, current research lacks a comparative exploration of strategies to combat collusive bidding through policy. Therefore, this study aims to identify more effective countermeasures by examining policy variations between regions with low and high incidences of collusive bidding. Using Latent Dirichlet Allocation (LDA) topic modeling, the study extracts key themes from these policies, while qualitative analysis highlights differences in approaches. It underscores that integrating electronic and information technology into bidding systems significantly reduces collusive practices. While increasing penalties can deter collusive bidding, achieving desired impacts requires thorough investigation and vigilant oversight. Additionally, strengthening external supervision enhances control over such activities. This study identifies critical governance strategies for addressing collusive bidding and advocates further research into more effective methods within the construction sector.

Keywords: collusive bidding; policy; government; text mining; comparation

1. Introduction

Collusive bidding is widely considered the most socially detrimental form of anticompetitive practice [1,2]. Construction projects obtained through collusive bidding often suffer from mismanagement and poor quality, leading to serious safety hazards and posing a threat to public security [3]. For instance, the collapse of a cooling tower during the construction of Phase 3 of the Fengcheng Power Plant in Yichun City, China, resulted in more than 70 fatalities; subsequent investigations revealed that this tragedy was caused by collusive bidding [4]. Similarly, the widely discussed “problematic road” project in Fuzhou City, China, with a total cost of 813 million RMB, experienced significant road surface subsidence of 30–50 centimeters and a qualified pile foundation rate of 0, both attributable to widespread collusive bidding [5]. Beyond these bad repercussions, collusive bidding also seriously disrupts the order of the construction market, inefficient allocation of market resources, and harms social and economic interests [6–8].

Policy measures serve as the foundation for governing collusive bidding and constitute an essential aspect of government governance [9]. Implementing well-thought-out and reasonable policy measures, along with establishing a comprehensive policy framework, can effectively deter collusion. Many researchers, therefore, have been focusing on how to fight for collusive bidding in the construction industry from the perspective of policy measures [6]. For instance, the researchers explored the influence of external environments on bidders’ collusive behaviors and aimed to

formulate the specific policies in different external environments, thereby enhancing the governance effectiveness of collusive bidding [10–12]. Some scholars discussed the punitive measures [13–15]. This is because punitive measures are the common tool used by governments to warn bidders to respect fair competition [16]. However, the current research has not extensively explored the measures for countering collusive bidding from a policy comparison perspective.

Policy comparison can offer in-depth analysis and insights, aiding decision-makers in gaining a better understanding of the impacts and outcomes of different policy measures [17]. In previous research, policy comparison has been frequently used to analyze different countries/regions to help the decision-makers develop more effective policy measures [11]. For example, Long et al. [11] compared seven selected national/regional drone regulations to identify the applicability of implementing the existing regulations in construction and aim to develop a multi-dimensional regulatory framework for using drones in the construction industry. Thus, to fill this gap, the study aims to develop more effective countermeasures against collusive bidding by examining the differences in policy measures with policy comparison.

In China, collusive bidding in the region of central China is higher than in the region of eastern China [10]. This is because eastern China, located in the socio-economically developed region, has more sound policies and bidding systems than the region of central China [11]. By comparing the policies of these contrasting regions, it becomes possible to discern the distinctions in policy approaches between areas characterized by low and high collusive bidding tendencies. Thus, this research compares the policies related to bid violations implemented in regions with low incidences of collusive bidding to those in regions with high incidences of collusive bidding. This analysis offers valuable insights into devising more efficacious strategies for curtailing collusive behaviors among bidders in regions where such practices are more prevalent.

2. Literature review

2.1. Collusive bidding in construction

Competition in the construction industry is known for its high levels of uncertainty, which leads to collusive bidding [11,18]. Collusive bidding refers to the behavior where two or more participants in the bidding process form an alliance to gain undue advantages [19]. They engage in irregular practices to control or influence the bidding outcome, causing financial losses to other participants. The establishment of collusive bidding requires three fundamental conditions: the presence of two or more participating entities, the ability to form subcontracts to distribute collusive gains, and the existence of negative externalities. Collusive bidding is mainly divided into three major categories: horizontal collusion, vertical collusion, and mixed collusion, as shown in **Figure 1**. The significant distinction among the three collusion forms lies in the involvement of different parties. Collusion between bidders is referred to as horizontal collusion; collusion between bidders and other stakeholders (excluding other bidders) is known as vertical collusion; and collusion involving bidders, other stakeholders, and other bidders is termed mixed collusion. Existing literature indicates that horizontal collusion is the most easily formed and also the most

severe form of collusion in the construction industry [7].

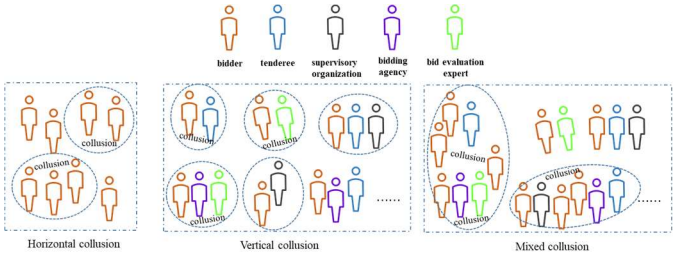

Figure 1. Types of collusive bidding.

Shi et al. [7] asserted that the primary factors encouraging collusive behaviors in bidding are the excessive competition and low profit margins experienced by contractors in the construction industry, which make them prone to engaging in collusive practices in markets with few competitors [20]. Moreover, larger firms tend to submit higher bids to seek higher profits [18], and their substantial market shares enable them to implement collusion strategies to maintain their competitive advantage. Bolotova et al. [21] verified the aforementioned claims and suggested that collusive behaviors in engineering are more likely to occur if the external environment incentivizes them to obtain higher profits. Dorée [22] exemplified the construction industry in the Netherlands to demonstrate that contractor greed is the primary driver of collusive behaviors in bidding. Moreover, businesses within the same region have more opportunities for business interactions, leading them to engage in private communications without arousing suspicion [23].

Some scholars present different perspectives on this matter. Ratshisusu [24] suggests that project scale can also lead to collusive behaviors in bidding. Morselli and Ouellet [18] argue that the composition of the construction market, consisting of a few large enterprises and a vast majority of small and medium-sized enterprises, is an important factor contributing to collusive bidding. Stigler [25] posits that market conditions, such as the number of competitors, barriers to entry, frequency of interactions, market transparency, demand growth and fluctuations, business cycles, market share distribution, and cost asymmetry, significantly influence the decision to engage in collusive practices. Wang et al. [26] and Oke et al. [27] unanimously agree that the main reason for the occurrence of collusive bidding is the inadequacy of punishment severity and regulatory oversight.

2.2. Measures for fighting collusive bidding

Prevailing research concerning the measures for fighting collusive bidding predominantly focuses on approaches that elevate the costs associated with collusion, diminish collusive gains, and bolster the intensity of oversight and punitive measures [28]. For instance, Allain et al. [29] argue that collusive governance should consider the economic environment and agents' risk preferences. Ratshisusu et al. [24] suggest that the owner's attitude significantly influences collusion among project participants, and different governance approaches should be adopted for various levels of collusion. Some scholars propose increasing the severity of penalties to reduce collusion occurrences [16,27,30,31]. In addition to increasing the punishment severity, Oke et

al. [27] recommend encouraging professionals to report suspicious activities and transactions, including collusion, implementing transparent and open procurement procedures for construction projects, and blacklisting professionals and companies found to be engaged in collusive behavior, revoking their registration to improve engineering performance and enhance the image of the construction industry.

Imposing administrative penalties on collusive bidders has been a common tool used by governments to warn bidders to respect fair competition [16,32]. For instance, France fined 21 construction companies 17.3 million euros for engaging in collusion during the bidding process for highway projects [27]. However, the proliferation of collusion cases indicates that the existing administrative penalties are still insufficient to deter collusive behaviors in engineering bidding [16]. Consequently, some scholars have discussed the optimal level of administrative penalties. Allain et al. [29] argue that the rational deterrence range for cartel fines should be significantly higher than the minimum threshold of administrative penalties, which is typically around 60%.

Existing research on collusive bidding monitoring methods primarily focuses on employing statistical methods to analyze the irregularities in bidders' quotations [33]. For example, Ballesteros-Pérez et al. [34] use the distribution of bid prices to detect abnormal collusive bidders. Erfani et.al [35] introduce a data-driven model called the Test of Abnormal Bid (TAB). This model employs Benford's law, a method commonly used for fraud detection in auditing and finance, to quickly identify price irregularities. Chotibhongs and Arditi [33] suggest that owners can refer to historical bidding data and use statistical tests to screen for suspicious collusive bidders. Porter and Zona [36] compared the cost structures of known collusive bidders and non-collusive bidders in highway construction projects and suggested analyzing anomalies in bidding to detect collusion. These studies indicate that collusive bidders' quotations differ from those of normal bidders, and this dissimilarity can be analyzed to identify collusive participants. In addition, other scholars have proposed alternative collusion monitoring methods. Padhi and Mohapatra [37] developed a control chart that directly detects colluders after bid opening, which was validated using engineering projects in India. Subsequently, they proposed controlling collusion during the procurement process by adjusting auction parameters [38].

3. Methodology

3.1. Policy text collection

According to the research of Wang et al. [1], Wang et al. [6], and China judgment online [11], collusive bidding cases are relatively less frequent in the eastern regions of China, specifically in Beijing, Shanghai, and Guangdong. In contrast, the central regions of China, particularly the provinces of Hunan, Hubei, and Jiangxi, have the highest number of collusive bidding cases. Therefore, this research selects Beijing, Shanghai, and Guangdong in the eastern regions as the comparative provinces/cities for the study. It compares the policy measures implemented in these three provinces/cities regarding bid-related illegal and irregular practices with those of Hunan, Hubei, and Jiangxi. The goal is to identify differences in policy measures and propose effective governance strategies to improve collusive bidding practices in China.

Peking University Legal Information Database (PULID), founded in 1985, is currently the most authoritative legal regulation information retrieval system in China [39]. Based on the selected provinces/cities, the research utilizes the official websites of local governments and the search function of the PULID; keywords such as "bidding," "collusion," "bid-rigging," and others were used to collect and compile relevant policy documents from the selected provinces/cities. A total of 36 policy documents were collected from Beijing, Shanghai, and Guangdong, while 16 policy documents were collected from Hunan, Hubei, and Jiangxi. The textual content of these policy documents serves as the primary material for policy analysis in this research.

3.2. LDA topic text mining

Latent Dirichlet Allocation (LDA) topic model is currently a hot topic in the field of text mining [40]. It is applicable for extracting topics and keywords from large-scale unlabeled documents and achieving document clustering [41]. The LDA model effectively handles dimensionality reduction of text content, integrating high-dimensional words into low-dimensional topics, thereby reducing the interference of noisy words, and facilitating the capture of key information and efficient classification of texts. This method is particularly suitable for mining topics in policy texts. Therefore, the research selects the LDA topic model as the primary method for policy text mining in this study.

The LDA topic model is a three-layer Bayesian probabilistic graph, consisting of document, topic, and word layers. The model can be applied to a single document or multiple documents, and it generates one or multiple topics and their corresponding words, following a multinomial distribution. Each topic is associated with a probability distribution over the words that describe the topic. LDA model structure diagram, as shown in **Figure 2**. In **Figure 2**, α represents the parameter of the Dirichlet prior on the per-document topic distributions. It controls the distribution of topics in each document. θ_{m} represents the topic distribution for document m. It is a vector that specifies the proportion of each topic within the document. $Z_{m,n}$ represents the topic for the nth word in the m_{th} document. It indicates which topic the word is associated with in the context of the document. $\omega_{m,n}$ represents the nth word in the m_{th} document. φ_k represents the word distribution for topic k. It is a vector that specifies the proportion of each word within the topic. β represents the parameter of the Dirichlet prior on the per-topic word distributions. It controls the distribution of words in each topic. The detailed process is as follows: (1) Sampling from the Dirichlet distribution α to generate the subject distribution θ_i of document i; (2) Sampling from the multinomial distribution θ_i of the topic to generate the subject $Z_{i,j}$ of the j-th word of document i; (3) Sampling from the Dirichlet distribution β to generate the word distribution $\Phi_{Zi,j}$ corresponding to the topic $Z_{i,j}$; (4) Sampling from the multinomial distribution of words $\Phi_{Zi,j}$ finally generates words $\omega_{i,j}$.

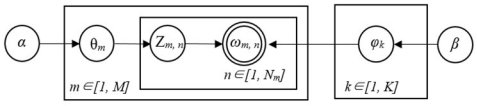

Figure 2. The basic logic of LDA.

In the training document set M, the joint distribution of known variables and hidden variables existing in the LDA model is as follows.

$$p(w_i, Z_i, \theta_i, \overline{\omega}|\alpha, \beta) = \prod_{i=1}^{N} p\left(w_{i,j}|\overline{\omega}_{Zij}\right)p\left(Z_{i,j}|\theta_i\right) \cdot p(\theta_i|\alpha)\, p(\overline{\omega}|\beta) \quad (1)$$

In Equation (1), N represents the total number of words in a document, and the maximum likelihood function estimation of document word distribution is:

$$P(w_i|\alpha, \beta) = \int_{\theta_i} \int_{\varphi} \sum_{Z_i} p(w_i, Z_i, \theta_i, \overline{\omega}|\alpha, \beta) \quad (2)$$

In the training process of the document set, the number of topics needs to be determined in advance, and the entire document set is used as the input content.

The most crucial step in LDA topic modeling is hyperparameter tuning, specifically the selection and determination of the number of topics K. The approach used to set the number of topics involves visualizing the results of the topic modeling in a two-dimensional space and observing the distances between topics and the degree of overlap. The LDAvis tool enables users to interactively adjust and identify the most useful words that represent specific topics, thereby improving the readability and distinctiveness of the topics. In this study, this method is employed to extract topic-representative words using the relevance formula:

$$r(w, k|\lambda) = \lambda\, log(\emptyset_{kw}) + (1 - \lambda) log\left(\frac{\emptyset_{kw}}{p_w}\right) \quad (3)$$

In the formula, *k* represents a specific topic, *w* represents a word, *r* represents the degree of association between the word and the topic, $\emptyset_{kw}$ represents the probability of word *w* in topic *k*, and λ is a variable parameter with a value between 0 and 1. When λ approaches 0, it indicates that topic-representative words have exclusivity (i.e., words that are more unique and specific to the topic have stronger relevance to that topic). When λ approaches 1, it means that words that appear more frequently in the topic can better represent that topic. By specifying a value for λ, the relevance between word *w* and topic *k*, denoted as $r(w, k|\lambda)$, can be adjusted.

3.3. Topic-generating procedure

In this study, most of the policy texts are full policy documents, containing numerous specialized terms and adhering to standard and continuous semantic expressions. To ensure that the final topics align with the research objectives, text preprocessing is necessary before generating the topics. The preprocessing steps mainly include tokenization and stop word filtering. The first task in file preprocessing is tokenization, and the accuracy of tokenization directly affects the quality of subsequent topic classification. Thus, the study uses the "jieba" tool for tokenization. From the tokenization results, it is evident that certain words such as "this regulation" and "this province" do not carry significant meaning in the policies. Hence, it is necessary to filter out stop words to reduce noise in the corpus. In Chinese text, stop words typically include punctuation marks, insignificant prepositions, interjections, etc. Additionally, in specialized research domains, certain words may have high frequencies but little actual significance. For instance, there might be an abundance of terms like "bidding and tendering", "bidding", and "tendering" in the text, which are

irrelevant to the policy analysis conducted in this research. Thus, the study employs the stop word filtering feature of the "jieba" tool. After text preprocessing, this study repeatedly adjusted the visualization results and underwent 50 rounds of iteration through multiple clustering processes to obtain the topic identification results related to collusive practices in collected policies. By setting the window and adjusting the λ parameter, the relevance of vocabulary to each topic was enhanced, ensuring a more descriptive representation of the respective themes. In this example, after multiple experiments, both texts' topic selection λ parameter was set to 0.4. The LDA topic model employed high-frequency keywords to describe the topics, and to ensure comprehensive topic descriptions, this study set the number of output keywords per topic to 30.

4. Results

The results of topic text mining for regions with fewer collusive practices in policy texts are shown in **Figure 3**, while the results for regions with higher collusive practices are presented in **Figure 4**. On the left side of both figures, the topic distance maps for the two contrasting texts are displayed. The LDAvis tool visually represents the distances between different topics in a two-dimensional vector space. The size of each circle represents the number of texts included in the corresponding topic. In the two-dimensional vector space, the seven topics show distinct differences and minimal overlap. The central positions of topics 1 to 7 are widely scattered and evenly distributed. This data result indicates that the designated categorization of the seven topics is acceptable. Among the seven topics in **Figure 3**, topic 1 has the highest text distribution, while topics 2, 3, 4, 5, and 6 exhibit relatively similar text quantities, and topic 7 has the lowest text distribution. In **Figure 4**, topics 1 and 2 have the highest text distribution, topics 3, 4, 5, and 6 have relatively similar text quantities, and topic 7 has the lowest text distribution.

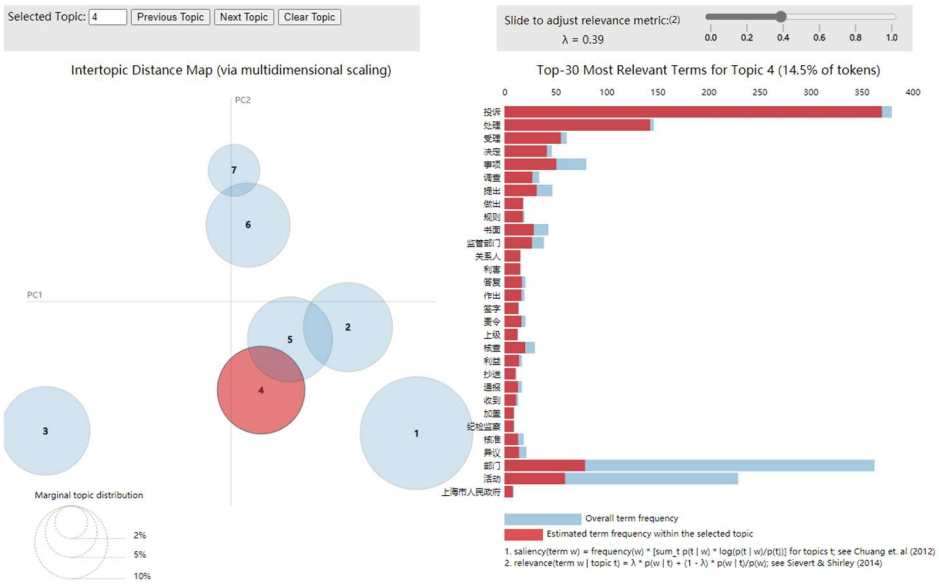

Figure 3. The inter-topic distance map and top-30 most relevant terms for topic 4 in the region of low collusive bidding.

Note: the Chinese in the image corresponds to Topic 4 in **Table 1**.

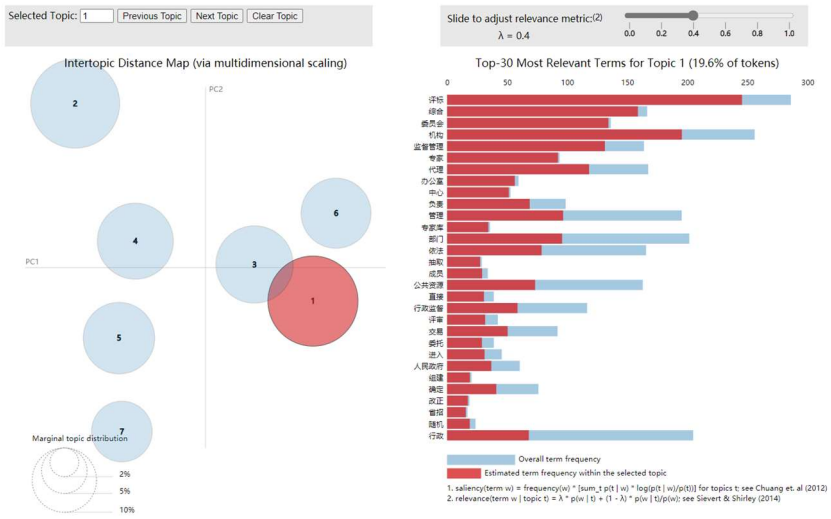

Figure 4. The inter-topic distance map and top-30 relevant terms for topic 4 in the region of high collusive bidding.
Note: the Chinese in the image corresponds to Topic 1 in **Table 2**.

Table 1 corresponds to the final topic classification results derived from **Figure 3**, which includes seven topics. From **Table 1**, it infers that the main topic words for Topic 1 consist of verbs such as "improve," "develop," "strengthen," "formulate," "perfect," "optimize," and nouns like "system," "mechanism," and "supervision." Therefore, this topic is summarized as "improve the system and supervision." Topic 2's main topic words are related to electronic systems, platform, and participants, leading to its summary as "electronic information platform." Topic 3 includes topic words primarily associated with fines, penalties, and violations, thus summarized as "punishment measures." The main keywords for Topic 4 pertain to complaints, regulation, verification, and notification, leading to its summary as "external regulation." Topic 5's keywords are mainly related to the normativity and integrity requirements of the bidding process, resulting in its summary as "integrity requirements for bidding process." Topic 6's keywords describe the requirements concerning bidding materials, thus summarized as "bidding material requirements." Topic 7's keywords are primarily related to the bidding process, such as evaluation location and bidding methods, leading to its summary as "bidding process requirements." Based on the results from **Figure 3** and **Table 2**, the importance of topics in policy texts from regions with fewer collusive practices can be ranked as follows: "improve the system and supervision," "electronic information platform," "punishment measures," "external regulation," "integrity requirements for bidding process," "bidding material requirements," and "bidding process requirements."

Table 2 presents the final topic classification results derived from **Figure 4**, encompassing seven distinct topics. Topic 1's main topic words primarily encompass various institutions, stages, and participants in the bidding process, leading to its summary as "bidding process." Topic 2 contains frequent keywords related to bidding materials, resulting in its categorization as "bidding material requirements." Topic 3 has a significant presence of words related to integrity and regulation, such as "dishonesty," "blacklist," "law," and "management." Therefore, this topic is summarized as "integrity and regulation." Topic 4 includes a substantial number of keywords associated with bidding projects and bidding requirements, leading to its

summary as “bidding requirements.” Topic 5’s keywords involve various government agencies, misconduct, evidence collection, and punishment-related terms, leading to its categorization as “violation handling.” Topic 6’s keywords are mainly related to the government and legal regulations, resulting in its summary as “government regulations.” Topic 7’s keywords encompass a wide range of content related to electronic and informational aspects. Therefore, Topic 7 is summarized as “electronic bidding platform.” Based on the results from **Table 2**, the importance of topics in policy texts from regions with higher collusive practices can be ranked as follows: “bidding process,” “bidding material requirements,” “integrity and regulation,” “bidding requirements,” “violation handling,” “government regulations,” and “electronic bidding platform”.

Table 1. The vocabulary distribution of different topics in the region of low collusive bidding.

Topic No.	Topic	Vocabulary
Topic1	Improve the system and supervision	Work, development, reform, supervision, department, mechanism, administrative supervision, regulation, strengthening, environment, field, formulation, system, improvement, notice, activity, market, optimization, development
Topic 2	Electronic information platform	procurement, expert, government, agency, platform, bid evaluation, electronic system, electronic, extraction, institution, system, Budget, expert pool, committee, irregularities, transaction system, commission, business
Topic 3	Punishment	Fine, discretion, amount, regulation, punishment, income, illegal, violation, division, disapproval, circumstances, confiscation, order, concomitant punishment, regulations, items, implementation, person in charge
Topic 4	External supervision	Complaint, processing, acceptance, decision, matter, investigation, proposal, making, rule, regulatory authority, related party, interest, reply, signature, order, superior, verification, notification, approval, objection
Topic 5	Integrity requirements	Management, publicity, candidates, credit, contract performance, information, results, bid winning, evaluation, construction, disclosure, contract, security deposit, announcement, proof, data, letter of guarantee, public resources, transaction, government affairs
Topic 6	Tender material requirements	Document, qualification, pre-examination, condition, method, spot check, law, catalog, modification, normative, plan, adoption, compilation, clarification, method, letter of commitment, review, regulation, announcement, requirement, filing
Topic 7	Bid evaluation related	Bid evaluation, bid opening, committee, evaluation, notification, name, violation, invitation, place, consortium, finance, notarization, members, contract, award, screening, address, name, organization, deadline

Table 2. The vocabulary distribution of different topics in the region of high collusive bidding.

Topic No.	Topic	Vocabulary
Topic1	Bidding process	Bid evaluation, committee, institution, supervision and management, expert, agent, office, center, responsible, management, department, law, members, public resources, administrative supervision, review, transaction, entrustment, government, expert pool
Topic 2	Tender material requirements	Qualification, examination, document, qualified, applicant, pre-examination, contract, announcement, conclusion, filing, deposit, post-examination, bid winning, submission, notice, bid winner, request, project, preparation, contract performance, agreement, submission for approval, selection, clear, agree, issue, evade
Topic 3	Integrity and Regulation	Project, engineering, regulation, activity, method, construction project, dishonesty, administration, blacklist, law, formulation, country, disclosure, public resource, management, approval, punishment
Topic 4	Bidder requirements	Registration, construction engineer, engineering, construction in progress, production, construction, license, interest, change, Damage, legal rights, post, construction project, division, maintenance, enterprise, remote, execution, key, professional, road, remote, Inquiry, security, validity period, experience
Topic 5	Punishment related	Housing, urban and rural construction, bad behavior, acquisition, records, supervision, identification, construction, cities, falsification, equivalent, punishment, commitment, reporting, defrauding, clues, civilization, construction bureau, construction office, proof
Topic 6	Government regulation	Funds, use, accountability, responsibility, violation, international, project, government, loan, state-owned enterprise, foreign, regulation, investment, law, scoring, appointment and dismissal, regulations, provincial organs, state, enterprise credit, supervision agency, aid, holding
Topic 7	Electronic bidding platform	Credit, evaluation, information, process, electronation, leakage, sharing, memorandum, serious demerit, disciplinary action, heavier, downgrade, dismissal, bad information, signature, transaction system, intelligent, public resource, warning, platform

5. Findings and discussion

The thematic analysis reveals that the region of low collusive bidding prioritizes continuous improvement and development of the bidding system and supervision. However, the highly collusive bidding area prioritizes the keywords of the bidding process. The policy texts related to electronic information platforms in regions with less collusion outdistance those in regions with high collusion. The results demonstrate that the widespread adoption of electronic and information technology in the bidding system positively impacts the governance of collusive bidding. This is because the integration of various modern collusive bidding monitoring technologies effectively reduces collusion occurrences. Nevertheless, the implementation of these regulatory technologies requires a unified electronic information platform. Thus, constructing an electronic information platform for bidding becomes crucial for effective digital collusion supervision. Ishii's [42] research found that the adoption of e-procurement may reduce bid rigging in public auctions by limiting in-person meetings of bidders. This study verified the above result in different ways. However, it is important to consider the cost of building digital supervision systems. The government should encourage R&D agencies to explore cost-effective techniques for digital supervision.

The study also finds that policy texts in regions with low collusion reference the investigation and punishment more. The finding means that the investigation and punishment have a specific deterrent effect on collusive bidding. Zhu et al. [9] propose a system dynamics model to present the deterrence of punitive measures. The results also verified that punitive measures could mitigate bidders' collusion behavior in the construction industry. Besides, Wang et al. [26] and Oke et al. [27] show that the main reason for collusive biding lies in the lack of punishment. Thus, some scholars suggest that the occurrence of collusive bidding can be reduced by increasing the punishment [27,30]. Wang et al.'s [41] research shows that the fine of the Chinese government to collusive bidders is much lower than the rational deterrence value. Therefore, the Chinese government should enhance penalties to mitigate bidders' collusion behavior. However, different countries may be facing different reasonable deterrent scopes due to various influencing factors, such as the economic level and social environment. Thus, the researchers should be doing more work to explore the reasonable deterrent scope by the character of their country's construction industry, thereby reducing bidders' collusive behaviors. Furthermore, these studies have overlooked the significance of thorough investigation. The research highlights the importance of directing attention towards probing instances of collusive bidding.

The study also shows that areas with lower collusive bidding focus more on external supervision, which means that strengthening external supervision positively affects the governance of collusive bidding. Regarding the external supervision, whistleblowing is one of the mechanisms for the internal control system to reduce the fraud [43]. From the extraction results of the subject words of the policy texts in areas with lower collusive bidding, it can be concluded that the whistleblowing occupies a very high proportion. In contrast, the ratio of policy texts in regions with frequent collusive bidding cases is meager. The above results show that whistleblowing is effective in the governance of collusive bidding. Therefore, this study believes that the

government should set up various convenient ways to actively encourage all parties involved, social figures, and the news media to report on collusion in project bidding and encourage whistleblowers to provide evidence that can evaluate the collusion between the reported persons. For example, filming the secret communication between colluding bidders, formulating bidding documents, distributing benefits, etc. In addition, the government should do an excellent job of protecting whistleblowers to ensure that whistleblowers perceive that their reporting behavior will not bring them adverse effects, such as when an online reporting platform is set up and whistleblowers can report anonymously. In addition, the exposure and credit mechanism can have a specific negative impact on colluding enterprises and form a particular warning effect on other enterprises. The credit record and exposure mechanism will affect the evaluation of the enterprise by the owner in the later bidding process. Consequently, this study suggests that the government can initiate an external supervision mechanism by implementing monitoring, reporting, and exposure systems. This mechanism would be led by the government and involve joint supervision by all relevant parties, including the public and the media.

6. Conclusions

Collusive bidding poses a significant threat to the health and sustainable development of the construction industry. The enactment of proficient policy measures is a potent means to alleviate collusive bidding within the construction sector actively. As such, this research analyses bidding policies between regions characterized by low and high instances of collusive bidding. By identifying disparities in policy contents, the study aims to identify efficacious governance strategies that are more effective to fight for collusive bidding in the construction industry. The research found that adopting an electronic bidding platform, imposing penalties for joining the investigation, and reinforcing external supervision are constructive forces in mitigating collusive bidding.

The research findings give policy insights into the most critical governance strategies for addressing collusive bidding from a policy-oriented perspective. The research findings also provide valuable guidance for researchers to further develop the more efficacious electronic bidding system integration of various modern collusive bidding monitoring technologies and suggestions in the development of external supervision.

It is important to acknowledge one limitation in this research. The policies collected in this study are from China, a vast nation comprising numerous provinces, each with its own distinct bidding regulations. These inherent attributes have significantly facilitated the completion of our research. However, some small countries may find it challenging to repeat this research in their countries due to the unavailability of data. Nonetheless, these nations can leverage the results derived from this study to formulate more effective methods for mitigating collusive bidding practices in their respective contexts.

Author contributions: Conceptualization, XW; methodology, XW and YZ; software, XW and YZ; validation, XW, YZ and KC; formal analysis, KC; investigation, YZ;

resources, XW; data curation, YZ; writing—original draft preparation, XW; writing—review and editing, KC and YZ; visualization, XW; supervision, XW. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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