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Identifying core policy instruments based on structural holes: A case study of China's nuclear energy policy

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ABSTRACT

Policy documents have become increasingly valuable in the field of bibliometrics because they contain important information such as the intentions and behaviors of policymakers. Policy instruments are the central elements of policy documents; therefore, identifying core policy instruments can help researchers in the field better understand the important methodological measures taken by government organizations to achieve specific economic or social goals. However, existing identification methods often focus on the effectiveness of a policy instrument along one dimension (e.g., economic indicators), while ignoring the relationship between individual policy instruments. This paper attempts to fill this gap by designing a network-based framework incorporating structural holes theory to identify the core policy instruments implied in the policy documents. We first identify "policy target-policy instrument" patterns in relevant policy documents and then establish a "policy target-policy instrument" network that maps onto real-world policy systems. Finally, using structural holes theory, we identify core policy instruments and analyze the policy mix system upon this basis. We use China's nuclear energy policy as a case study to evaluate the proposed approach. Our proposed method is useful for quantitatively analyzing complex policy systems and for identifying core policy instruments and targets within them.

1. Introduction

Policy bibliometrics is the quantitative study of public policy documents. It is a quantitative analysis of the contents and structural attributes of policy that combines unique historical and social contexts to reveal changes and trends in policy themes, the selection and application of policy instruments, as well as the distribution and game theoretic strategies of special interests in the policymaking process. Policy documents are the basis of policy bibliometrics since they are the "carriers" of policy and they provide a tool for people to examine the details of policy and legislation (Gao & Tisdell, 2004). Policy documents contain specific consistent features (such as policy title, name of issuing institution, ID number, issuing time, and citations of other policies) which make it possible and reasonable to use bibliometric methods in policy analysis (Huang et al., 2015). Policy documents are also an important research subject in altmetrics (Bornmann & Haunschild, 2018).

Identifying core policy instruments implied in policy documents is crucial for policy bibliometric research and public policy analysis research. Policy instruments are a set of tools and methods used by the government or other relevant policy-

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making organizations to achieve specific policy targets. The identification of core policy instruments in a policy domain can help researchers understand the key measures, overall policy distribution, and the development trend of policy measures in policy system. This may further help policymakers better understand policy processes, the relationships and influences between policy instruments, and provide a stronger foundation for subsequent policy designs.

A policy text (or document) may contain multiple policy instruments. The aggregation of policy documents constitutes a policy mix system, which inevitably contains series of interacting policy instruments. As the number of promulgated policies increases, the corresponding policy mix system also becomes increasingly complex. In this policy system, one policy instrument may address multiple policy targets. One policy target may also be resolved by multiple policy instruments. Therefore, it is difficult to systematically ascertain which policy instruments are the core policy instruments of a policy mix.

Researchers who have attempted to address this question have used methods such as case studies (Tambach & Visscher, 2012), interview analysis (Kocsis & Hof, 2016), and literature reviews (Gren, 2008). Others have evaluated and identified core policy instruments based on summary statistics that quantitatively describe or summarize features of policy-related samples and observations (Feldman & Kelley, 2006; Kocsis & Hof, 2016; Marbe & Harvey, 2005). Still others have used econometric methods to study the effects of various policy instruments, including using a Cross-Sectionally Augmented Distributed Lags (CS-DL) estimator (Minniti & Venturini, 2017), ordinary least squares (OLS) time series regressions (Cantner, Graf, Herrmann, & Kalthaus, 2016), and a consumer diffusion model (Stoneman & Battisti, 1998). Network-based methods also provide a way to discern and illustrate relationships between different policy elements, and can thus be used to identify core policy instruments (Cantner et al., 2016; Hird & Pfotenhauer, 2017; Luukkonen & Nedeva, 2010). Though progress has been made in various ways to identify core policy instruments, one remaining issue is that previous research has focused on assessing the effectiveness of the policy instruments in a subjective manner, while there is much less quantitative analysis of the interactions among policy instruments from a network relationship perspective (i.e., in the process of identifying core policy instruments, the location and interrelationship of each policy instrument on the policy mix network is not considered).

In order to address this shortcoming in the existing study, we designed a network-based framework incorporating structural holes theory to identify the core policy instruments implied in the policy documents. We first collected relevant policy documents related to our selected policy theme, and then identified "policy target-policy instrument" patterns from policy documents. These patterns were used to identify the relationships between specific policy elements (i.e., the policy targets and policy instruments). Furthermore, using these "policy target-policy instrument" patterns, we constructed a "policy target-policy instrument" network that reflects important features of real-world policy mix. Then, we identified core policy instruments based on the theory of structural holes. The advantage of our proposed approach is that provides a quantitative assessment of the relationship among policy instruments in a policy mix system from a network perspective based on structural holes theory, and then identifies the core policy instruments within the policy network.

Structural holes is a concept in social network research that suggests that actors in a social network hold certain advantages or disadvantages based on how they are positionally embedded in social network structures (Burt, 1995). A structural hole is defined as a gap between two actors that have complementary sources of information but are not directly connected. Ronald Stuart Burt argued that the actors that occupy more structural holes are in a more advantageous position for realizing their objectives. We use this theory here to evaluate the competitive advantage of certain policy instrument in a policy mix.

This paper is organized as follows: We review the previous studies in Section 2. Our method for identifying core policy instruments is presented in Section 3. A case study of China's nuclear energy policy is used to verify the effectiveness of our method in Section 4. Finally, we conclude our research, pointing out limitations and future research directions in Section 5.

2. Literature review

Existing studies on policy document analyses and core policy instrument identification approaches are reviewed below.

2.1. Bibliometric study of policy documents

Policy documents serve many purposes: policy planning, enforcing codes of conduct, providing guidance and structure to governing, etc. Existing bibliometric policy research can be reviewed from four perspectives:

2.1.1. Analyses based on external attributes of policy documents

The most common external attributes of policy documents include the policy issuing date, issuing department, type of policy, etc. Huang et al. (2015) analyzed policies from various departments across different time periods to identify trends in the evolution of China's science and technology innovation policies. Saidi, Salie, and Douglas (2017) explored changes in the policy framework based on Kingdon's policy streams theory. Other studies have focused on policy document reference. For example, Bornmann, Haunschild, and Marx (2016) used the number of academic article citations in policy texts to assess the influence of specific types of research. Similarly, Ritter and Lancaster (2013) measured the impact of research based on the references used in policy texts.

2.1.2. Analyses based on linguistic elements

Linguistic elements (e.g., words, phrases, and sentences) in policy documents can also be used to analyze the intention of policy designers. Laver, Benoit, and Garry (2003) extracted keywords from legislative speeches of different parliamentarians to statistically analyze their policy positions. Roberts, Wentz, and Edwards (2006) studied the World Health Organization (WHO) and Global Road Safety Partnership (GRSP) based on word frequency statistics and revealed points of divergence in road safety policies. Hernandez, Cooper-Searle, Skelton, and Cullen (2018) also quantitatively assessed the importance of energy and environmental issues in EU politics based on word frequency statistics. Van Dijk (1997) used the identification of the word "other" in parliamentary records to explore implicit discrimination against ethnicity minorities. Some researchers have also focused on the phrasal or linguistic characteristics of policy texts. Bhatia (2006) identified the linguistic style of communiques from bilateral meetings, i.e. whether the style was affirmative, persuasive or avoidant, and use this factor to examine the attitudes of national leaders towards international events.

2.1.3. Semantic analysis of policy texts

The semantic analysis of policy includes topic analysis, keyword or concept pattern-based policy analysis. Huang, Su, Xie, and Li (2014) collected over 4,000 Chinese science and technology (S&T) policies, identified keywords for each policy, and then performed a detailed topic analysis based on keyword co-occurrence networks. Cassi, Lahatte, Rafols, Sautier, and de Turckheim (2017) compared scientific publications with policy documents based on a topic model approach. In addition, other researchers have attempted to identify particular conceptual patterns implicit in policy texts and have used them as the basis of policy analyses. Policy instruments are typically studied in this context. Analyzing the mix of policy instruments and how they change over time can reveal generalizable principles about how policy instruments are implemented, thus laying the foundation for evaluating the impact of policies. Jordana, Fernandez, Sancho, and Welp (2005) identified and analyzed policy instruments in Internet-related policies and found that focused and mixed policy interventions were important factors in promoting the increase of Internet users. McWilliam, Brown, Eagles, and Seasons (2015) and Zhang, Xu, Sun, and Elahi (2018) both used content analysis to perform policy analyses: the former examined Chinese photovoltaic-based targeted poverty alleviation policies, while the latter examined Ontario's local policies about protecting designated green infrastructure from the negative impact of residential encroachment. Lehtoranta, Nissinen, Mattila, and Melanen (2011) identified policy instruments and used them to analyze the impact of different policy instruments on the industrial symbiosis system.

2.1.4. Network theory-based analysis

The policy system can be viewed as a network of policy elements (e.g., policymakers, policy implementers, policy targets, policy instruments, etc.). Based on a policy network, researchers can analyze multiway relationships among various policy elements. Some policy researchers have noted that networks among policy issuing entities can be used to explore the relationship among different policymaking organizations (Snijders, 2005) or various public service organizations (Provan & Kenis, 2008). For our purposes here, the most critical of these are governmental inter-agency collaborative networks (Huang et al., 2015; O'Leary & Bingham, 2009). Similar to uncovering citation relationships among papers, there are also often citation relationships among policies (implicit in the policy text, often expressed in unstandardized formats). Such citation relationships then can be used to construct policy citation networks. Huang et al. (2015) used this type of network to assess the impact of China's S&T policies on industry, markets and society.

2.2. Identifying core network nodes and application of structural holes theory

2.2.1. Identifying core network nodes

There are a number of ways to measure the core/importance/centrality of a node in a social network (Bordons, Aparicio, González-Albo, & Díaz-Faes, 2015). The most common indicators are: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. The simplest approach is using degree centrality, which is the number of edges that a node has (Golbeck, 2013). The higher degree centrality, the greater number of edges a node has. While degree centrality is simple and effective, it cannot indicate the importance of a node in connecting other or how central it is to the main group. Closeness centrality addresses this problem by emphasizing that important nodes tend to be close to all other nodes, i.e., closeness centrality is the average of the shortest path length from one node to every other node (Golbeck, 2013). Going even further, betweenness centrality measures how much a given node is in-between other nodes. This metric is assessed by the number of shortest paths that passes through the target node (Perez & Germon, 2016). However, all of these methods take less account of the characteristics of a target node's neighboring nodes. Eigenvector centrality emerged as a resolution to this, as it considers the fact that a node could have high importance (and thus, a very high eigenvector centrality) if it is connected to other very well-connected nodes (Hansen et al., 2020). As social network analysis continues to evolve, new algorithms are emerging. The PageRank algorithm is a variant of eigenvector centrality, but it primarily considers the number of in-bound links, the quality of the linkers, and the link propensity of the linkers (Page, Brin, Motwani, & Winograd, 1999). Han et al. (2018) has also used the dynamic equilibrium of social networks to identify a core node set in a social group.

2.2.2. Application of structural holes theory

Structural holes theory was introduced by Ronald Stuart Burt and was used to identify actors who hold certain advantages in social network (Burt, 1995). Since then, there have been several practical applications of structural holes theory (Chen et al., 2009; Guan, Yan, & Zhang, 2017), especially in the business management and investment-related research: Hao et al. (2020) used structural holes theory to identify threshold effects of R&D investment intensity. In a similar vein, Liu, Qu, and

Scherpereel (2020) used an analysis based on structural holes theory to examine how the role positioning of investment institutions influences the value of start-up enterprises. Some researchers have gone further and considered the impact of geographic advantages on business investment; for example, Swierczek (2020) explored the ability of the actor sitting on the structural hole to attain additional rent. Hu, Chang, and Lin (2020) identified the best tour service center locations based on structural holes theory. Other researchers have focused on the structural features of abstract networks in business analyses, for example, Bai, Wu, Liu, and Xu (2020) used structural holes theory to study the impact of global innovation network on industry performance.

In addition to work related to business analysis, structural holes theory has also been applied to the social sciences: (1) Decision making: Cheng, Cheng, Zhou, and Wu (2020) proposed a weight allocation method with structural holes theory to optimize the process of group decision-making in a social network. (2) Knowledge management and information exchange: Liu and Zhu (2020) developed a structural-holes-based framework to help co-workers strategically leverage their network relationships to facilitate tacit knowledge application and integration in complex inter-organizational arrangements. Li and Xu (2020) aimed to improve information exchange among doctors in e-health communities by using structural holes theory. The theory of structural holes is still evolving, especially in the field of structural hole detection and identification, for example, by using community forest models (Zhang et al., 2020), conductance and degree scores (Liao, Gu, Fan, Zhang, & Tang, 2020), weighted meta paths (Yang, Zhang, Chen, Zhou, & Kong, 2020) and other approaches. The practical application of this theory will be further expanded as it is applied to more research areas.

2.3. Identifying core policy instruments

Policy instruments can be characterized by a set of different rationale and targets that typically come from different administrative levels. These instruments interact with each other in a complex policy mix system and their characteristics significantly complicate how policy instruments are evaluated. Though it is difficult to fully examine any policy system, many researchers have tried to first identify core policy instruments. At present, policy instrument evaluation methods can be divided into the following five categories:

2.3.1. Qualitative methods

Many researchers have attempted to identify core policy instruments in a policy system using qualitative methods. Murphy, Meijer, and Visscher (2012) took the energy performance of existing private dwellings in the Netherlands as a case study to qualitatively assess the impact of different policy instruments. Similarly, Tambach and Visscher (2012) evaluated policy instruments in the Dutch energy-neutral new housing development programme using a case study approach. Metz and Ingold (2014) conducted an in-depth literature analysis and developed a framework that integrated the policy problem and sustainability dimensions to assess the effectiveness of different policy instruments in pollution control. Kocsis and Hof (2016) assessed the effectiveness of two instruments (production subsidies and DEN-B) based on existing evaluations, which were complemented by interviews. Gren (2008) presented an economic analysis (based on a literature review and qualitative analysis) on how to set targets and tools for mitigating damage from invasive animal species. Egmond, Jonkers, and Kok (2005) attempted to uncover policy instruments that are most suitable for an intervention strategy based on the "precede-proceed" model of behavioral change. Based on an overview of different policy programs, Eickelpasch and Fritsch (2005) investigated the advantages and problems of a new policy instrument called "cooperation-contest programs". Magro and Wilson (2013) proposed a six-step "mixed evaluation protocol" to evaluate individual policy instruments. Kivimaa and Kern (2016) developed a novel policy instruments analytical framework which included the two policy system dimensions of creation and destruction, and subsequently found that ideal policy mixes include "creative destruction" behavior. Autant-Bernard, Fadairo, and Massard (2013) explored how regional innovation policies support knowledge-generating and learning institutions based on empirical results related to knowledge spillovers. One experimental study is also worth mentioning. Bruggemann and Meub (2017) implemented a creative real effort task, simulating a sequential innovation process, and analyzed the effectiveness of different policy instruments in supporting innovative behavior.

2.3.2. Descriptive statistics

Descriptive statistics provide quantitative summaries that describe features of data samples, and have been used by a number of scholars as a main way to evaluate policy instruments. Marbe and Harvey (2005) used GateCycle, a power plant simulation program, to examine which policy instruments best promoted the construction of pressurized gasifier units and which combinations of policy instruments promoted the integration of a biofuel gasifier. Kocsis and Hof (2016) built an evaluation framework to analyze the extent to which Dutch energy policy instruments contributed to achieving policy goals when strong empirical evidence was lacking. The framework involved a few distinct steps in identifying which variables could measure policy instrument effectiveness: collecting the data, summarizing insights from the academic literature, and lastly, assessing policy instrument effectiveness. Feldman and Kelley (2006) used questionnaire data to perform a set of descriptive statistics to estimate the relationship between project characteristics and R&D subsidies.

2.3.3. Econometric analyses

Researchers have also applied econometric methods (e.g., multiple linear regression models) to analyze the effects of various policy instruments. Veugelers (2012) designed a Flemish Community Innovation Survey eco-innovation module to analyze the effects of different policy tools. Minniti and Venturini (2017) assessed the long-term growth effects of policy instruments on business R&D, using the Cross-Sectionally Augmented Distributed Lags estimator (a novel regression technique) and adopting a Schumpeterian growth theory. Using multiple linear regression, Sierzchula, Bakker, Maat, and van Wee (2014) sought to determine the relationship of policy instrument (consumer financial incentives) and the adoption of electric vehicles. Kiyono and Ishikawa (2013) determined which combinations of environment regulation instruments emerged as a subgame of perfect Nash equilibrium and explored the incentives of different countries to choose a policy instrument in a two-stage policy choice game. Costantini, Crespi, Martini, and Pennacchio (2015) explored the different impact of demand-pull and technology-push policies in shaping technological patterns in the biofuels sector, using a baseline model. Scandura (2016) used an OLS regression to explore the impact of publicly-funded university-industry collaboration policy instruments on R&D efforts in UK firms. Guerzoni and Raiteri (2015) designed a quasi-experimental framework to empirically analyze the impact of various technological policies on the innovative behavior of firms. Fabrizi, Guarini, and Meliciani (2018) adopted a theoretical framework of the knowledge production function to analyze the impact of regulation policies on environmental innovation. Spyridaki, Banaka, and Flamos (2016) applied a multi-criteria analysis to assess policy tools that were effective in fostering energy efficiency in Greece. Based on an instrument variable regression analysis, Wolff and Reinthaler (2008) investigated the effectiveness of public subsidies on enterprise research at a macroeconomic level, using a set of panel data from 15 OECD countries. Based on a consumer diffusion model, Stoneman and Battisti (1998) evaluated a fiscal incentives policy instrument and found that it was not very useful in promoting the use of unleaded fuel. Stucki, Woerter, Arvanitis, Peneder, and Rammer (2018) investigated the effects of different policy instruments on the creation of green energy products based on Tobit regressions. Using the spatial dynamic panel data method, Montmartin and Herrera (2015) evaluated in-country and out-of-country effects of both R&D subsidies and fiscal incentives on business-funded R&D.

2.3.4. Network-based methods

The advantages of network-based methods can be harnessed to explore the relationship between policy elements, and can also be used specifically to identify core policy instruments. Cantner et al. (2016), for instance, measured the characteristics of a network to study the effects of single policy instruments as well as changes in policy cooperation networks in the wind power and photovoltaic sectors in Germany. Based on researcher co-authorship networks, patent activity analysis, and cost analysis, Taylor, Rubin, and Hounshell (2003) examined the relationship between policy instruments and innovation related to the environmental control technology used in coal-fired power plants in the U.S. Luukkonen and Nedeva (2010) used networks of institutions and individuals to assess which policy instrument can increase the level of integration in academic research. Falcone, Lopolito, and Sica (2018) combined social network analysis and fuzzy inference simulations to identify adequate policy instruments for fostering energy transition. Hird and Pfotenhauer (2017) combined a network bibliometrics with quantitative analyses to evaluate the impact of complex international capacity-building partnerships, which they define as an emerging policy instrument.

2.3.5. Hybrid approaches

Some researchers have combined several established quantitative and qualitative methods to identify core policy instruments in a policy system. For example, Taylor et al. (2003) analyzed government actions, patent activity, technology cost trends, knowledge transfer activities (researcher co-authorship networks), and expert elicitations, to identify which policy instruments have a greater effect on sulfur dioxide control technology innovation. Based on a Community Innovation Survey, descriptive statistics and a Tobit model, Aschhoff and Sofka (2009) quantitatively compared the effects of four policy instruments (i.e., government procurement, regulation, university research support, and R&D subsidies) on the innovation success of over a thousand firms in Germany. Hird and Pfotenhauer (2017) proposed a novel mixed-method approach, including a bibliometric network analysis, a difference-in-difference program evaluation, statistical matching, and system architecture analysis, to explore the influence of complex international capacity-building partnerships as an emergent policy instrument for forming research clusters and re-orienting current research.

In general, although previous studies have focused on how to identify core policy instruments, certain methodological limitations still exist: (1) The bulk of the previous literature has only assessed the effectiveness of the policy instruments themselves, and do not quantitatively consider the relationship between policy instruments in a policy mix network. In fact, a number of different policy instruments in policy system can interact to promote the achievement of one or more policy targets. It is insufficient to evaluate the effect of a single policy instrument on an entire policy system. (2) Data accessibility: Qualitative or econometric researches require a large number of case studies and/or empirical data. However, it is often not easy to obtain such large data samples, especially during the early stages of policy implementation.

3. Methodology

We propose a network-based framework incorporating structural holes theory to identify the core policy instruments implied in the policy documents. First, the relevant policy documents are collected and the “policy target-policy instrument” patterns in those documents are extracted. Second, a “policy target-policy instrument” network is constructed based on these patterns. Finally, core policy instruments implied in policy documents are identified based on structural holes theory. This framework is summarized below (Fig. 1).

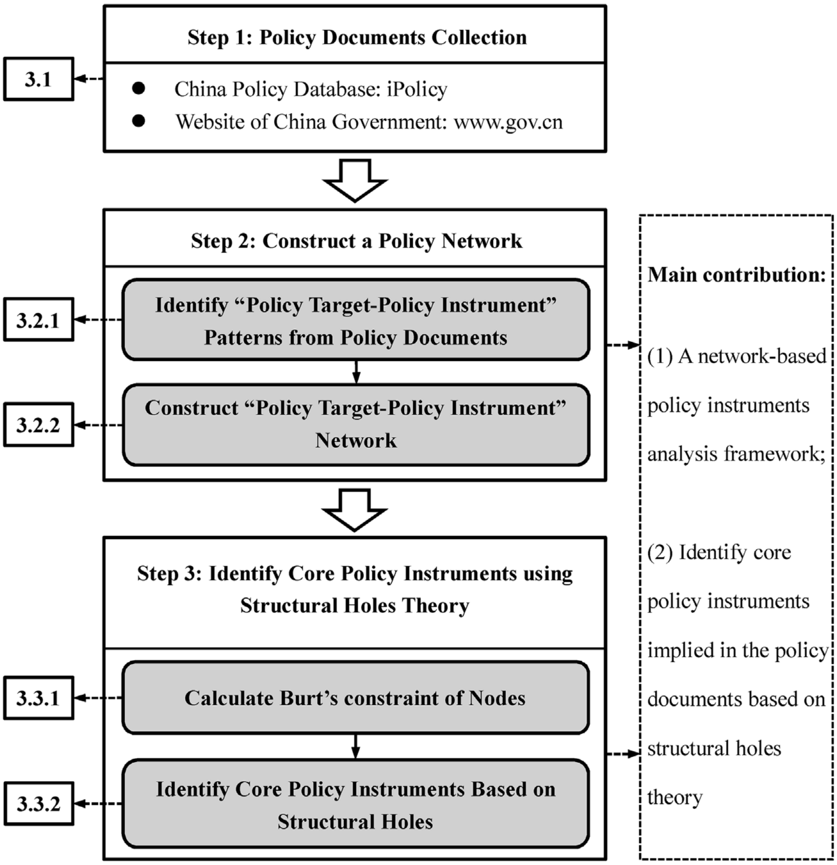


Fig. 1. Framework for identifying core policy instruments.

3.1. Data collection

Policy documents provide foundational data for quantitative policy research. They may include agenda blueprints, political leaders' speeches, communiques, regulations, reports, and laws issued by policymaking organizations or politicians. In this paper, data collection proceeded as follows:

(1) Determine the data source based on our specific research needs. Government websites often publish relevant policy texts and other commercial companies and scientific research institutions also have databases of policy texts.
(2) Construct a list of initial search terms, and then obtain the initial set of policy text data based on these initial search terms.
(3) Invite experts in the field to examine the initial set of policy text data, and then modify (add or delete) search terms based on expert opinions.
(4) Based on the final search terms in step (3), yield new sets of policy text data. Steps (3) and (4) are iterative.
(5) Preprocess the new data set. Some policies have full texts related to the target policy field, but other may only have a few paragraphs that are relevant. Therefore, the following preprocessing steps were taken: 1) If a policy title contained a search term, that policy text would be retained in the data set; 2) If the policy title did not contain a search term but the body contained a search term, then only the paragraph that contained the search term would be added to the final data set.

3.2. Constructing a policy network

The following steps were taken to construct a policy network: (1) Identify "policy target-policy instrument" patterns from policy documents, which we elaborate on below; (2) Construct a "policy target-policy instrument" network based on the obtained patterns.

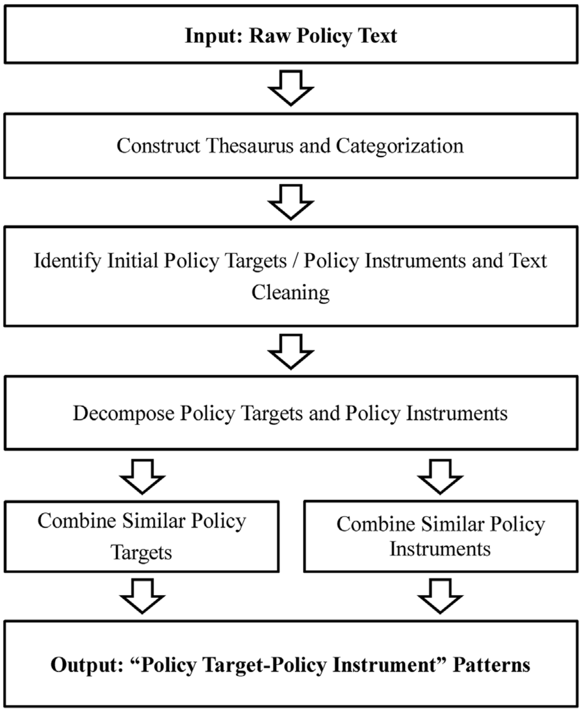


Fig. 2. Steps for identifying "policy target-policy instrument" patterns.

3.2.1. Identifying "policy target-policy instrument" patterns

A "policy target-policy instrument" pattern is a pair of expressions (a two-element structure that contains a pair of phrases) extracted from policy texts, e.g., "promote the development of nuclear energy technology" and "setting technical standards for nuclear energy." In this example, "promote the development of nuclear energy technology" is a policy target which refers to the purpose of the policy. "Setting technical standards for nuclear energy" is a policy instrument that suggests a series of tools and actions used by the policymaker to achieve the goal.

The specific steps for identifying "policy target-policy instrument" patterns (Fig. 2) are the following: (1) Construct thesauruses (verbs and nouns) of policy targets and policy instruments. In the Chinese policy literature, policy targets often appear in this form, e.g., "to achieve/promote the development of nuclear energy technology". So the policy target thesaurus is mainly composed of verb phrases, such as "to achieve..." . Construction of the policy instruments thesaurus is more complex. We adopt Rothwell and Zegveld's approach to define and classify policy instruments (Rothwell & Zegveld, 1985), that is, dividing policy instruments into three categories: supply-side policy instruments, environmental policy instruments and demand-side policy instruments. Each category has its own subcategories, e.g., demand-side instruments include price subsidies, tax incentives, government procurement, etc. while environmental instruments include technical standards, intellectual property rights, etc., and supply-side instruments include technology input, information service, financing support, etc. We therefore developed a thesaurus for each policy instrument subcategory. For example, the common verbs and nouns for technical standards policy instruments included formulation technical standards, establishment safety standards, improvement ... standards, etc. (2) Retrieve and identify initial policy targets and policy instruments in policy documents based on the constructed thesauruses. We design a rule-based policy target recognition algorithm based on our thesauruses and the expressed features (e.g., grammatical structure) of the policy targets in the texts, which allows us to identify a large number of policy targets in bulk. For policy instruments, we first find the locations of possible policy instruments in the text, based on the policy instruments thesauruses, and then filter out the obvious non-policy instrument expressions based on the policy instrument text features. The remaining policy instruments are then manually identified and collected, with the support of expert knowledge. For example, we can locate a series of texts that indicate a high chance of being technical standards policy instruments, based on their corresponding thesauruses, and then we filter out the non-technology-specific textual errors, and finally identify, for example, the "setting technical standards for nuclear energy" policy instrument, which gets screened by experts at the final step. (3) Clean the initial policy targets and policy instruments by removing stop-words, combining words based on word stems, and consolidating synonyms. (4) Decompose complex policy targets and policy instruments. Each policy target (or policy instrument) may contain multiple sub-policy targets/instruments. These complex policy targets/instruments) are decomposed in order to improve the precision of the identification process. For example, "establishment of nuclear energy production and nuclear waste management mechanisms, and setting technical standards for nuclear energy" is a complex policy instrument. We will split it into three separate policy instruments: "establishment of nuclear energy production management mechanisms," "establishment of nuclear waste management mechanisms," and "setting technical standards for nuclear energy." (5) Combine similar policy targets or policy instruments. For example, the policy instrument "setting technical standards for nuclear energy" has the same content as the expressions "building technical standards for nuclear energy production and management", so we integrate these two expressions into one, i.e., "setting technical standards for nuclear energy." (6) Identify "policy target-policy instrument" patterns based on their co-occurrence relationship in the full text or individual paragraph of a policy document. It should be noted that comprehensive macro-policy targets usually appear in the introductory section of a policy document. This policy target and each policy instrument within the same document would then most likely form a policy target-policy instrument pair. The processes, algorithms, and thesauruses summarized above have been used by our group to develop a policy target identification and preprocessing software (PolicyAnalyser).

3.2.2. Constructing the "policy target-policy instrument" network

Based on the "policy target-policy instrument" patterns identified in Section 3.2.1, we build a "policy target-policy instrument" network which can model real-world policy systems. The network construction procedures are as follows: (1) Every policy target or instrument is one node. The node size is proportional to the frequency of occurrence of the corresponding policy element. (2) If a certain "policy target-policy instrument" pattern exists, then an edge is drawn between the target and instrument nodes.

The "policy target-policy instrument" network demonstrates universal patterns of real policy mix, i.e., a policy mix is formed by a series of interacting policy instruments, involving policy actors at different hierarchies and spanning multiple policy domains, all with the aim of achieving one or more policy targets. Therefore, we can conduct a series of policy analyses based on this network.

3.3. Identifying core policy instruments

We leverage structural holes theory to identify the importance and competitive advantage of policy instrument nodes. We selected this theory because it explores how an actor acquires information and resources to behave and employ its abilities in a complex network environment, all from the perspective of the attributes and position of a node in an actor network (Burt, 1995). This is very similar to the reality of policy mix networks, where the implementation of a policy is dependent on the interactions and collaboration between policy targets and policy instruments that are relevant to it, and where the information and resources available to the policy instrument form the foundation of its functions (i.e., defining its effectiveness). In contrast to other theories and indicators in complex networks (e.g., degree centrality, closeness centrality, betweenness centrality, eigenvector centrality, the PageRank algorithm), an approach that considers the importance of nodes in terms of "information and resources" is more consistent with real-world policy networks, where different policy instruments occupy different resources and information, have different capabilities, point to different policy targets, and yet collaborate with each other to achieve comprehensive policy planning. Structural holes theory can help researchers take these policy network characteristics into account. More traditional approaches identify core policy nodes from a centrality perspective, which does not account for the resource appropriation of a node or interaction and collaboration among nodes, while also glossing over considerations of the overall realization of the networks' macro goals. Therefore, from a theoretical point of view, the structural holes approach is stronger than traditional approaches that use centrality to identify core policy instruments.

Based on the "policy target-policy instrument" network described in Section 3.2.2, we compute Burt's constraint score for all nodes in order to identify the core policy instruments in the network. The steps below detail how we identify the core policy instruments.

3.3.1. Calculating Burt's constraint score for nodes in the network

In the actor network, a "structural hole" is defined as a gap between two actors that have complementary sources of information but are not directly connected to each other. Based on structural holes theory, if a structural hole exists between actors, then their contributions to the network are cumulative or even complementary. Burt argues that if an actor occupies structural holes then it has an "advantage", making it more likely to achieve its goals. Specifically, the term "advantage" refers to the fact that the node occupies more information and material resources, and that its location gives it better control over the resource flow between nodes. These nodes enjoy more of their own development opportunities, which is conducive to the realization of their goals. We therefore call these "core nodes".

In this paper, since the subject of research is a policy network (specifically, the policy target-policy instrument network), the "actor" here is a policy instrument. The defining characteristics of a core policy instrument that occupies a structural hole in the policy network are the following: 1) Irreplaceability: Core policy instruments that occupy structural holes are non-repetitive. When implementing a macro-level policy target, this node would represent the only policy instrument that can bridge different policy targets and policy instruments. 2) Strong opportunities for development: Core policy instruments can garner more government support and therefore increasing chances of being implemented. 3) Core policy instruments have a significant impact on other nodes in the policy network and thus control the development of the entire network. For example, if there are three policy instruments A, B, and C (indirectly connected through a series of nodes), and C occupies the structural hole between A and B, while A and B have similar capabilities, then policy instrument C ultimately determines whether A or B gets adopted. This is because, according to the structural holes theory, instrument C, because of its location, occupies the resources and information required for further development of policy instruments A and B. Policy instrument C would therefore have a significant impact on other nodes and it controls the development of the entire network, and would be considered a core policy instrument. These three characteristics are consistent with the characteristics of the nodes that occupy structural holes in structural hole theory. Therefore, the nodes that occupy structure holes in a policy network are core policy instruments.

We use Burt's constraint to measure the degree to which a node occupies a structural hole. This was proposed by Ronald Stuart Burt to be a commonly used algorithm for measuring the competitive advantage of nodes based on structural holes theory. Burt's constraint score is calculated based on three network features: size, density, and hierarchy. It measures the extent to which resources are concentrated in a community. When the score is low, a node has a greater chance of occupying structural holes (i.e., becoming a bridge that connects nodes) and gaining a competitive advantage (Burt, 2010). Burt's constraint score is derived from the following:

1) Degree of constraint between two actor nodes:

$$C_{ij} = \left(P_{ij} + \sum_{q} P_{iq} P_{qj}\right)^2 \tag{1}$$

In Eq. (1), q is the intermediate node between i and j, such that i and j are connected through q. P_{ij} is the ratio of the relationship strength (direct connection) between i and j, to the sum of the relationship strength (direct connection) between i and the other nodes. The same principles are used to calculate P_{iq} and P_{qj}:

$$P_{\mathrm{ij}} = \frac{RS_{\mathrm{i \to j}} + RS_{\mathrm{j \to i}}}{\sum_{\mathrm{x} \in \mathrm{V}[i],\, x!=i} \left(RS_{\mathrm{i \to x}} + RS_{\mathrm{x \to i}}\right)} \tag{2}$$

$$P_{\mathrm{iq}} = \frac{RS_{\mathrm{i \to q}} + RS_{\mathrm{q \to i}}}{\sum_{\mathrm{x} \in \mathrm{V}[i],\, x!=i} \left(RS_{\mathrm{i \to x}} + RS_{\mathrm{x \to i}}\right)} \tag{3}$$

$$P_{\mathrm{qj}} = \frac{RS_{\mathrm{q \to j}} + RS_{\mathrm{j \to q}}}{\sum_{\mathrm{x} \in \mathrm{V}[q],\, x!=q} \left(RS_{\mathrm{q \to x}} + RS_{\mathrm{x \to q}}\right)} \tag{4}$$

$RS_{\mathrm{x \to y}}$ is the weight of the edge between node x and node y, which is the frequency of the "policy target-policy instrument" pattern corresponding to the x-y node pair.

2) Burt's constraint score for each node:

$$C_i = \sum_{j} C_{ij} \tag{5}$$

$C_i$is the constraint score of node i. A low score implies that node i has a higher possibility of occupying a structural hole and becoming the core node in a policy network.

3.3.2. Identifying core policy instruments based on structural holes theory

The policy instrument nodes in our network are sorted based on Burt's constraint scores. Policy instruments with a low score have a greater possibility of becoming a bridge between nodes; that is, these policy instruments have a greater chance of occupying the structural holes. These policy instruments are therefore considered core policy instruments in the network and policy documents.

4. Case study: nuclear energy policy in China

We use China's nuclear energy policies as a case study to test the reliability of the proposed method for identifying core policy instruments. Energy has been a key part of social development in China, but the generation and consumption of energy often lead to environmental pollution issues (Huang et al., 2012). To this end, the Chinese government has promulgated a series of supporting policies to promote the healthy development of the nuclear energy industry.

4.1. Data collection and policy network construction

This paper uses two data sources: iPolicy and www.gov.cn. iPolicy is a policy text database developed by the Center for Science, Technology & Education Policy at Tsinghua University. Since 2005, over 1.2 million structured public policy documents issued since 1949 have been collected from the Chinese government at all levels. The web address for data storage and for our analysis platform is the following: http://39.105.58.246/ipolicy (new users must register to create an account). This platform offers such as "Co-word Analysis" and "Topic words recognition." Policy text data can be downloaded in bulk by contacting the development platform and obtaining advanced user rights. Our second data source is the official Chinese government website (www.gov.cn), which is hosted by the State Council General Office of China. This website provides a platform for government departments to publish various policy documents.

Based on these two data sources, we retrieve central government-level nuclear energy policy texts (i.e., policies issued by State Council and related ministries) from 1949 to 2017. The types of policy documents include official strategy outlines, governance plans, programs and guidelines. The specific data retrieval steps are as follows: (1) We first collected policy documents with text containing the term "nuclear energy." (2) Then, we retrieved policy documents containing the following in the titles: "program", "strategy", "plan", "scheme", "guiding opinion", and "agreement." (3) After a manual inspection of these documents, we created a new list of search terms to further obtain a new set of policy text data. (4) Finally, based on the new data set, and after data preprocessing and expert screening, we obtained 78 policy documents for our case study. Using the method described in Section 3.2, we identified 118 policy targets and 214 policy instruments, which formed 1,762 "policy target-policy instrument" patterns.

Based on the "policy target-policy instrument" patterns described above, we then construct a "policy target-policy instrument" network (Fig. 3). The specific method here is as follows:

(1) As we build the "policy target-policy instrument" patterns, we enter this data into a table as node pairs, and this table (not shown here but was completed in the background) forms the foundation of our "policy target-policy instrument" network. The table contains 1,762 rows and two columns, where each row represents a "policy target-policy instrument" pattern, the first column of the table is the policy target, and the second column is the policy instrument. We also have a table to store the occurrence frequency of the policy targets and instruments.
(2) Import the lists obtained in step (1) into Gephi to generate the "policy target-policy instrument" network (as shown in Fig. 3). In this network, green nodes are the policy targets and red nodes are the policy instruments. The node sizes represent usage frequency/number of occurrences. The number on each node is the identification number of the policy targets (or instruments). The connection between nodes indicates that the two nodes constitute a "policy target-policy instrument" pattern.

As Fig. 3 shows, some policy instruments only address a few policy targets, while other policy instruments are simultaneously related to multiple policy targets. In general, there are three types of patterns in the relationships between the policy target set and the policy instrument set: 1) A small number of policy instruments addressing a large number of policy targets. For example, policy instrument no. 277 addresses a range of policy targets such as nos. 45, 70, 12, 7, etc. (bottom middle of Fig. 3), many of which has only one policy instrument, no. 277; 2) A large number of policy instruments addressing a small number of policy targets. For example, policy instrument nos. 207, 131, 241, 266, etc. all address policy target no. 13 (top right of Fig. 3), and many of them address only one policy target, no. 13; 3) An equilibrium state, where the number of policy targets and corresponding policy instruments do not differ much. For example, policy instrument nos. 322, 321, 147, 139, 142, etc. are designed to address policy target nos. 17, 23, 9, 101, 98, etc. (bottom left of Fig. 3).

4.2. Identifying core policy instruments based on structural holes theory

Based on structural holes theory, we identify core policy instruments and analyze the results with respect to their distribution characteristics, core system composition, and application characteristics.

4.2.1. Core policy instrument identification

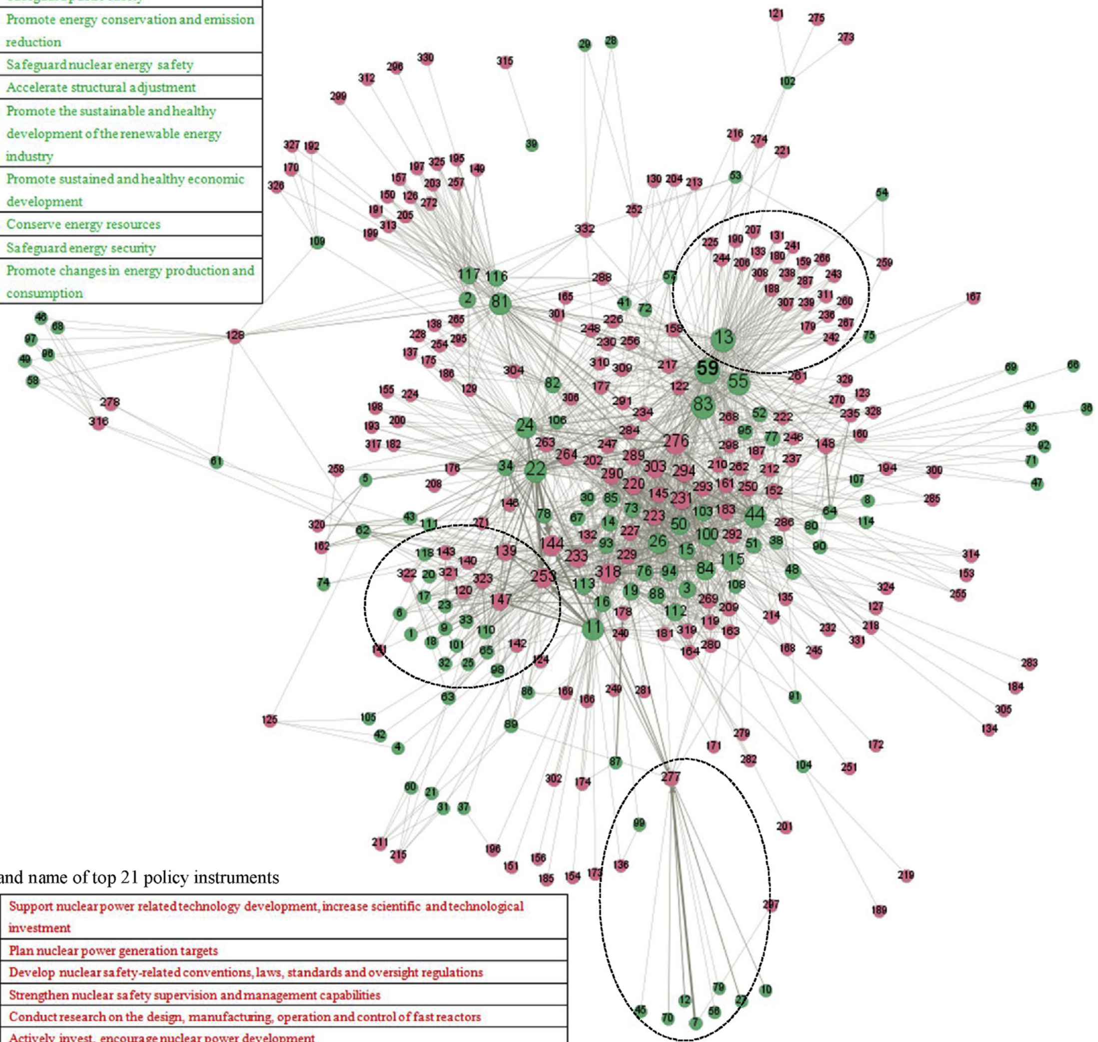
Based on the acquired policy networks, we identify core policy instruments in the field of Chinese nuclear energy policy using structural holes theory. We compute Burt's constraint scores (i.e., the degree of occupying structural holes) for each node in the policy network. Finally, we rank all the policy instruments based on their constraint scores (shown in Table 1). A lower Burt's constraint score indicates that a policy instrument has more advantages and is more important in the network. Table 1 lists the top 10 core policy instruments in our case study network, as well as the top three policy targets that correspond to those policy instruments. The sorting criteria for policy targets are based on the "policy target-policy instrument" pattern frequency: higher co-occurrence frequency means that the policy target is more directly related to the policy instrument. In cases where co-occurrence frequency is the same, we took the policy target with the highest frequency.

4.2.2. Results analysis 1: distribution characteristics of China's nuclear energy core policy instruments

Based on the identified core policy instruments (shown in Table 1), we find that China's nuclear energy policy has a clear bias in the selection and application of policy instruments. In terms of different types of policy instruments, among

*ID and name of top 10 policy targets

11	Promote environmental protection
22	Safeguard public safety
16	Promote energy conservation and emission reduction
24	Safeguard nuclear energy safety
44	Accelerate structural adjustment
7	Promote the sustainable and healthy development of the renewable energy industry
14	Promote sustained and healthy economic development
113	Conserve energy resources
26	Safeguard energy security
84	Promote changes in energy production and consumption



*ID and name of top 21 policy instruments

276	Support nuclear power related technology development, increase scientific and technological investment
318	Plan nuclear power generation targets
144	Develop nuclear safety-related conventions, laws, standards and oversight regulations
253	Strengthen nuclear safety supervision and management capabilities
231	Conduct research on the design, manufacturing, operation and control of fast reactors
303	Actively invest, encourage nuclear power development
233	Conduct nuclear accident research, improve nuclear accident emergency management capabilities
264	Promote nuclear legislation related work
234	Conduct technical research related to nuclear safety
289	Develop spent fuel and radioactive waste reprocessing technologies
294	Study and master the core technologies of fast reactor designs
122	Develop the nuclear energy industry at the chain and market levels
220	Construct demonstration projects
147	Develop oversight regulations related to nuclear safety
217	Construct scientific experimental facilities for nuclear physics
223	Construct high-temperature gas-cooled reactor demonstration projects
250	Conducting research on high-temperature gas-cooled reactor technology
139	Develop nuclear power regulations
152	Strengthen the construction of national key science and technology projects for large and advanced pressurized water reactor nuclear power plants
284	Conduct in-depth research and development of advanced nuclear fuel technologies
290	Develop small reactor technology

Fig. 3. China's nuclear energy policy network.
*The nodes with red border label are the policy targets. The nodes with yellow border are the policy instruments.

the core policy instruments, there are five supply-side instruments, four environmental instruments, and one demand-side instrument. Therefore, we can see that supply-side instruments and environmental instruments play a greater role in the policy network. The role of demand-side instruments, such as government procurement, price subsidies and tax incentives, are relatively weak. Demand-pull policy instruments do not have an advantage in this network. In terms of the sub-categories of the policy instruments, there are four scientific and technological investment plans, three target plans, one technical support document, one demonstration project, and one regulation. This shows that the proportions of "science and technology investment" and "target planning" policy instruments are the largest. At the same time, policy instruments such as "technical support", "demonstration project", and "regulations" are also taken into account in the policy network.

From the perspective of the subject matter of policy instruments, **nuclear energy technology-related policies** form the core of the policy network. There are five directly relevant policy instruments: "support nuclear power related technology development and increase technology investment", "research the design, construction, operation and control of fast reactors",

Table 1
Top 10 core policy instruments.

ID	Core Policy Instruments	Main Category and Subcategory	Burt's Constraint Score	Corresponding Core Policy Targets (IDs within parentheses)
276	Support nuclear power related technology development and increase technology investment	Supply side instruments; Technology investment	0.025877	Accelerate structural adjustment (44); safeguard public safety (22); Safeguard nuclear energy safety (24)
318	Plan nuclear power generation targets	Environmental instruments; Target planning	0.030273	Promote environmental protection (11); Accelerate structural adjustment (44); Promote energy conservation and emission reduction (16)
233	Carry out nuclear accident research to improve nuclear accident emergency management capabilities	Supply side instruments; Technical support	0.03125	Safeguard public safety (22); Promote environmental protection (11); Safeguard nuclear energy safety (24)
231	Research the design, manufacturing, operation and control of fast reactors	Supply side instruments; Technology investment	0.032986	Safeguard energy security (26); Develop clean energy (50); Promote changes in energy production and consumption (84)
294	Study and master the core technologies of fast neutron reactor designs	Environmental instruments; Target planning	0.036049	Safeguard energy security (26); Develop clean energy (50); Promote changes in energy production and consumption (84)
303	Actively invest, encourage the development of nuclear energy	Supply side instruments; Technology investment	0.037293	Accelerate structural adjustment (44); Safeguard energy security (26); Promote changes in energy production and consumption (84)
220	Construct demonstration projects	Demand side instrument; Demonstration project	0.038549	Safeguard energy security (26); Promote changes in energy production and consumption (84); Develop clean energy (50)
264	Promote nuclear power-related legislation work	Environmental instruments; Regulations	0.039486	Safeguard public safety (22); Safeguard nuclear energy safety (24); Maintain social harmony and stability (111)
253	Strengthen nuclear safety supervision and management capabilities	Environmental instruments; Target planning	0.040985	Promote environmental protection (11); safeguard public safety (22); Safeguard nuclear energy safety (24)
289	Research and develop spent fuel and radioactive waste treatment technology	Supply side instruments; Technology investment	0.041636	Promote environmental protection (11); safeguard public safety (22); Safeguard nuclear energy safety (24)

"study and master the core technologies of fast neutron reactor design", "actively invest, encourage the development of nuclear power", and "research and develop spent fuel and radioactive waste treatment technology." Among these core policy instruments, two technologies are particularly noteworthy: fast reactors and spent fuel reprocessing. There are two policy instruments that focus on "fast reactors" and one policy instrument on "spent fuel reprocessing". **Nuclear energy safety-related policies** are another core group of policies in terms of the subject matter of the policy instruments. Three policy instruments directly related to it: "Carry out nuclear accident research, improve the ability of emergency management of nuclear accidents", "strengthen nuclear safety supervision and management capabilities", "research and develop spent fuel and radioactive waste after-treatment technology." Nuclear safety is therefore a core issue in the development of nuclear energy in China, and relevant policy instruments have been carefully designed by policymakers with this in mind. It therefore represents another group of core policy instruments.

In terms of the main focus of China's nuclear energy policy targets, the following appear to be priority issues: safeguarding public safety; promoting environmental protection; promoting changes in energy production and consumption; safeguarding nuclear energy safety; promoting energy conservation and emission reduction; accelerating structural adjustment; and maintaining a harmonious and stable society while developing clean energy. These results imply that the main issues nuclear energy development in China to be solved by core policy instruments are those related to safety and environmental protection. Interestingly, Fig. 3 shows that "increasing independent innovation capability (59)", "promoting the energy technology revolution (83)", "giving science and technology innovation a leading role in overall innovation (55)", "promoting the development of science and technology (13), and "promoting the development of nuclear power (81)" are policy targets with

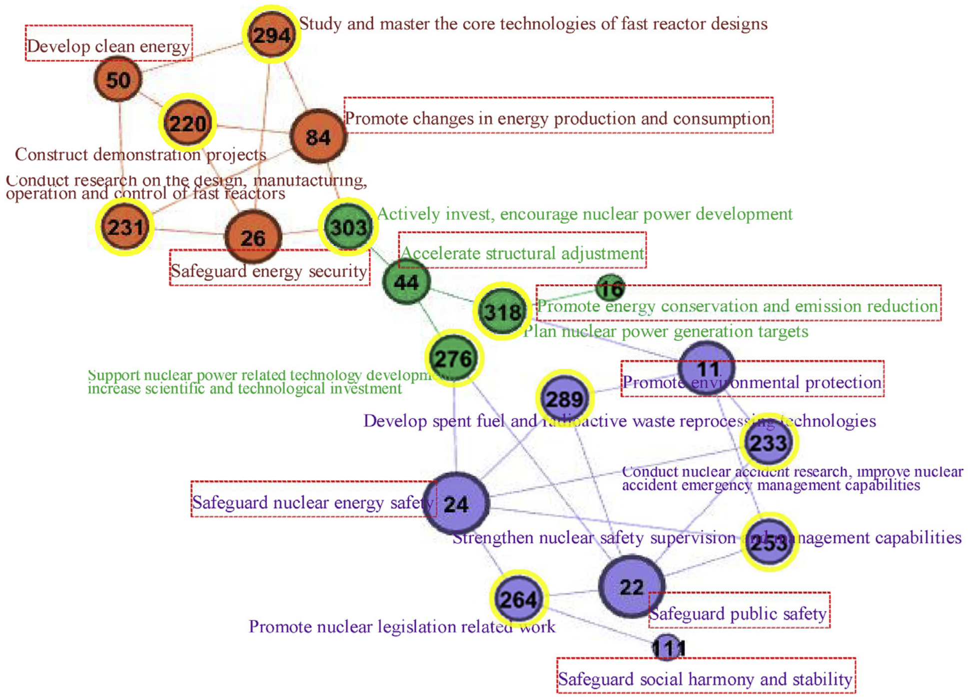


Fig. 4. The core of China's nuclear energy policy network.

the highest frequency of occurrence. These targets are macro-level policy goals and are mostly technical. However, these targets do not appear in Table 1; that is, they are not the most relevant targets of the core policy instruments we found. This suggests that the policy targets of the core policy instruments are more specific than macro-level policy goals, and the emphasis is mostly on energy safety and environmental protection. In other words, the core policy instruments are more oriented towards practical policy responses instead of macro planning.

4.2.3. Results analysis 2: China's nuclear energy core policy system composition

The policy mix theory states that no policy exists in isolation, and for a policy to be most effective, it needs to be supported, have interactions with, and be complemented by a series of related policies, all of which can be expressed through the cooperation and interaction among a series of policy targets and policy instruments. Inevitably, there will also be a core system of policy targets and policy instruments that dominate the planning and implementation of the entire policy system, which we refer to as the "core policy system" in this paper. By identifying the core policy system, it is easier for policy researchers and policymakers to grasp the key points of policy planning and implementation, identify breakthroughs and footholds for solving problems, and promote cooperation among policies to form a virtuous policy cycle.

Based on the identified core policy instruments and their key policy targets (see Table 1 and Fig. 3), we unpack the core policy system of China's nuclear energy policy as the following (Fig. 4):

(Note: Each sub-branch of the policy system is expressed as: **policy target - policy instrument + policy instrument + policy instrument +**. . .):

a) Accelerate structural adjustment (44) - Support nuclear power related technology development, increase scientific and technological investment (276) + Plan nuclear power generation targets (318) + Actively invest, encourage nuclear power development autonomy (303)
b) Safeguard public safety (22) - Support nuclear power related technology development, increase scientific and technological investment (276) + Conduct nuclear accident research, improve nuclear accident emergency management capabilities (233) + Promote nuclear power related legislative work (264) + Strengthen nuclear safety supervision and management capabilities (253) + Develop spent fuel and radioactive waste reprocessing technologies (289)
c) Safeguard nuclear energy safety (24) - Support nuclear power related technology development, increase scientific and technological input (276) + Conduct nuclear accident research, improve nuclear accident emergency management capabilities (233) + Promote nuclear power related legislative work (264) + Strengthen nuclear safety supervision and management capabilities (253) + Develop spent fuel and radioactive waste reprocessing technologies (289)
d) Promote environmental protection (11) - Plan nuclear power generation targets (318) + Conduct nuclear accident research, improve nuclear accident emergency management capabilities (233) + Strengthen nuclear safety supervision and management capabilities (253) + Research and develop spent fuel and radioactive waste reprocessing technology (289)

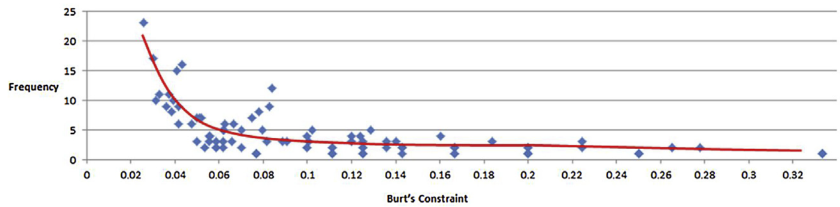


Fig. 5. Distribution of occurrence of policy instruments in China's nuclear energy policy network based on Burt's constraint scores.

e) Promote energy conservation and emission reduction (16) - Plan nuclear power generation targets (318)
f) Safeguard energy security (26) - Conduct research on the design, manufacturing, operation and control of fast reactors (231) + Study and master the core technologies of fast reactor designs (294) + Actively invest, encourage the development of nuclear power (303) + Construct demonstration projects (220)
g) Develop clean energy (50) - Research the design, manufacturing, operation and control of fast reactors (231) + Study and master the core technologies of fast reactor designs (294) + Construct demonstration projects (220)
h) Promote changes in energy production and consumption (84) - Conduct research on the design, manufacturing, operation and control of fast reactors (231) + Study and master core technologies of fast reactor designs (294) + Actively invest, encourage nuclear power development (303) + Construct demonstration projects (220)
i) Safeguard social harmony and stability (111) - Promote nuclear legislation related work (264)

Fig. 4 shows that the core system of nuclear energy policies in China constitutes a small policy network. The system has nine policy targets, four of which are safeguarding nuclear energy and public and social safety (b, c, f, i), while the remaining four are related to ecological protection and low-carbon energy (d, e, g, h), except for item a, which focuses on industrial restructuring. The key policy instruments used to achieve these policy targets focus on "technological innovation", "investment in research", and "investment in science and technology." These policy targets and policy instruments are interconnected to jointly promote the development of the nuclear energy industry.

4.2.4. Results analysis 3: application characteristics of China's nuclear energy policy instruments

The overall distribution of policy instruments is plotted in Fig. 5. Each point on the graph is a policy instrument. The x-axis values are Burt's constraint scores for each policy instrument, and the occurrence frequency of the policy instrument is on the y-axis. As can be seen in the figure below, there is a power function relationship between Burt's constraint score and the occurrence frequency of China's nuclear energy policy instrument. Assuming that Burt's constraint score is variable x, occurrence frequency is variable y, while $x > 0$ and $y > 0$, then the relationship between x and y is similar to the power function, $y = x^a$, where $a < 0$. Specifically, as the Burt's constraint score of a policy instrument increases, the frequency of its occurrence (use) decreases. In other words, the more central and dominant the policy instrument (with a lower Burt's constraint score), the more likely it is to have a higher frequency of use, which is consistent public policy researchers' and policymakers' expectations of the policy process. We suspect that this situation is related to the characteristics of policy formulation and implementation in China: the Chinese policy process generally follows a pattern of small-scale experiments, followed by a period of identifying and summarizing the problems that arose, then modifying and improving those issues, and finally, scaling up policies. In this process, efficient and advantageous policy instruments are reused, while ineffective instruments are gradually withdrawn, resulting in the power function relationship shown in Fig. 5. This also indirectly validates the effectiveness of our core policy instrument identification algorithm.

4.3. Comparison with the traditional network centrality indicator

To verify the applicability of the structural hole theory, we compared the different core policy instruments identified by the traditional network centrality indicator and the approach proposed in this paper. The reason why we chose eigenvector centrality is that the algorithm emphasizes that the importance of a node depends not only on the number of its neighbor nodes, but also on the importance of its neighbor nodes. This is consistent with the feature that "the importance of a policy instrument also depends on the importance of the other policy targets or policy instruments with which it is associated". The specific comparison process is as follows:

(1) Identify the TOP 30 core policy instruments by the proposed method in this paper (i.e., based on structural hole theory) and eigenvector centrality indicators respectively.
(2) Compare the differences of the two results. Specifically, we find that some of the core policy instruments identified by the two methods are consistent, so to compare the strengths and weaknesses of the two results, we need to compare the difference of the two results (i.e., those policy instruments in the TOP 30 core policy instruments identified by the two methods that are inconsistent). Therefore, we present the unique core policy instruments identified based on structural hole theory (denoted as Group A) in Table 2 and the unique core policy instruments identified based on the eigenvector

Table 2
Unique core policy instruments identified based on the structural holes theory (Group A).

ID	Unique Core Policy Instruments	Centrality of the Issuing Agency	Degree of collaborative implementation (the Number of Collaborative Issuance)	Centrality of policy targets (the Number of Occurrences of Policy Targets)
147	Establish nuclear safety-related supervision and management regulations	Core issuing agencies (the State Council agencies): 7; Sub-core agencies (ministries and commissions): 0	0	109
148	Establish standards for nuclear power technology	Core issuing agencies (the State Council agencies): 1; Sub-core agencies (ministries and commissions): 5	1	72
263	Promote “Go Out” strategy of nuclear power and strengthen nuclear power exports	Core issuing agencies (the State Council agencies): 3; Sub-core agencies (ministries and commissions): 3	1	55
152	Strengthen the National S&T Major Project for Large Advanced Pressurized Water Reactor Nuclear Power Plant	Core issuing agencies (the State Council agencies): 5; Sub-core agencies (ministries and commissions): 1	0	47
323	Draft regulations for emergency management of nuclear power plant nuclear accidents	Core issuing agencies (the State Council agencies): 4; Sub-core agencies (ministries and commissions): 0	0	88
	Total	Core issuing agencies (the State Council agencies): 20 Sub-core agencies (ministries and commissions): 9	**2**	**371**

Table 3
Unique core policy instruments identified based on the eigenvector centrality (Group B).

ID	Unique Core Policy Instruments	Centrality of the Issuing Agency	Degree of collaborative implementation (the Number of Collaborative Issuance)	Centrality of policy targets (the Number of Occurrences of Policy Targets)
210	Construct pressurized water reactor demonstration project	Core Issuing agencies (the State Council agencies): 4; Sub-core agencies (ministries and commissions): 1	0	49
209	Construct CAP1400 demonstration project	Core Issuing agencies (the State Council agencies): 1; Sub-core agencies (ministries and commissions): 2	1	57
262	Master the key technology of modular small stack	Core Issuing agencies (the State Council agencies): 2; Sub-core agencies (ministries and commissions): 1	0	44
284	Deepen research and development of advanced nuclear fuel technology	Core Issuing agencies (the State Council agencies): 5; Sub-core agencies (ministries and commissions): 1	0	58
119	the installed nuclear power generation operating capacity strives to reach 58 million kilowatts and the installed nuclear power generation under construction reaches more than 30 million kilowatts in 2020	Core Issuing agencies (the State Council agencies): 0; Sub-core agencies (ministries and commissions): 2	1	53
	Total	Core Issuing agencies (the State Council agencies): 12; Sub-core agencies (ministries and commissions): 7	**2**	**261**

centrality (denoted as Group B) in Table 3. In total, there are 10 core policy instruments that differ among the TOP 30 core policy instruments.

(3) Conduct a comparative analysis of the core policy instruments in Group A and Group B from three perspectives: the centrality of issuing agency of the policy instruments, the degree of collaborative implementation of policy instruments, and the centrality of policy targets. Among them:

The "centrality of the issuing agency of the policy instrument" (corresponding to column 3 of Tables 2 and 3) is calculated by counting the nubmber of high level issuing agencies of the policy instruments. Add "1" to the count of "centrality of the issuing agency" every time when the policy instrument is issued by the State Council or the Standing Committee of the National People's Congress; On the other hand, if the policy instrument is issued by ministries and commissions, the count of "sub-core agency" is increased by 1. The "core agency" and "sub-core agency" for these policy instruments are summarized in the last row of the table under "Total". In general, the higher the "centrality of the issuing agency", the more important and advantageous the policy instrument is. Such policy instruments are issued by core agencies, which means they tend to have higher priority, greater access to and control over other resources and information, and easier control and influence over policies issued by other lower-level agencies.

The "Degree of collaborative implementation of policy instruments" (corresponding to column 4 of Tables 2 and 3) is determined by calculating the number of times the policy instrument has been collaboratively implemented, i.e., the number of collaborative issuances of the policy instruments. Every time when a policy instrument is issued by two or more agencies, add "1" to the "Degree of collaborative implementation of policy instruments". In general, the higher the "degree of collaborative implementation", the more important the policy instrument is. The implementation of a policy instrument is often dependent on the coordinated actions of multiple agencies, so a policy instrument with a collaborative relationship at the issuing stage is often more advantageous and more likely to be implemented successfully. At the same time, policy instruments that the government values and has high expectations for are often implemented in a collaborative manner in order to promote their success.

The "centrality of policy targets" (corresponding to column 5 of Tables 2 and 3) is calculated by the number of occurrences of the policy targets corresponding to this policy instrument, with a high number of occurrences indicating that the policy target is frequently emphasized by government agencies and therefore corresponds to a high centrality. Generally speaking, the higher the centrality of the policy target, the more important the policy instrument is. This is because the government tends to match the most important policy target with a more central and certain policy instrument in the policy making process, and also gives the most attention and support to the policy target and the corresponding policy instrument in the subsequent policy implementation process. Therefore, such policy instruments are more advantageous and can more easily perform its function.

The comparative analysis of Tables 2 and 3 reveals that 1) Compared to the core policy instruments based on eigenvector centrality, the results identified based on structural hole theory are more often issued and implemented by the State Council and the Standing Committee of the National People's Congress (there are 20 core issuing agencies in Group A, while only 12 core issuing agencies in Group B). Moreover, there are more sub-core agencies in Group A (numbers: 9) than in Group B (numbers:7). Therefore, the core policy instruments identified based on the structural hole theory (group A) have easier access to relevant resources and information because of their hierarchical advantages, and are more capable of influencing and controlling the issuing and implementation of other policies at lower levels. 2) The policy instruments in groups A and B are very similar in terms of the degree of collaborative implementation. 3) Compared to the core policy instruments based on eigenvector centrality, those identified based on structural hole theory have more important "policy targets" (The value of policy target centrality for group A is 371, while the value for group B is 261), which indicates that policy instruments in group A are more oriented towards core policy targets than those in group B, i.e., policy instruments in group A focus on what the government cares most about. Such policy instruments and policy targets are more central and irreplaceable in the implementation process, and they are more likely to be supported and assisted by government departments, thus obtaining strong opportunities for development.

Therefore, in general, the method proposed in this paper for identifying core policy instruments based on the structural hole theory outperforms the method that based on the eigenvector centrality.

5. Conclusion and future directions

In this paper, we proposed a network-based framework incorporating structural holes theory to identify the core policy instruments implied in the policy documents. First, we collected policy documents and identified "policy target-policy instrument" patterns within relevant policy documents. Second, a policy network was constructed based on these patterns. Third, using structural holes theory, we identified core policy instruments in the policy mix network. The proposed method has the following advantages: (1) "Policy target-policy instrument" patterns have great potential to describe the core components of a policy text. (2) The proposed method can quantitatively identify relationships among policy instruments based on policy network and structural holes theory. (3) The proposed method does not require post-assessment data (e.g., econometric data, patents data) and can be used to predict the effectiveness of policy instruments at the beginning period of an issued policy. (4) Obtaining objective and reproducible results, reducing subjectivity and ambiguity in public policy research. The method proposed in this paper has practical implications for policymakers and researchers by allowing policy instruments to be analyzed based on network dimensions. The purpose of this paper is to identify the mechanisms by which policy targets and policy instruments are related to each other, and then to identify the core policy instruments in a policy system, thus laying the foundational groundwork for subsequent policy evaluation. At the same time, our method provides a theoretical basis for policymakers to carry out future policy designs and to implement policy instruments from a network perspective.

To validate the effectiveness of our method, we carried out an analysis of China's central-level nuclear energy related policies. Through our case study, we identified core policy instruments and high-performance policy target-policy instrument mixes. These can be used to elucidate the path of China's nuclear energy development and guide the next generation of nuclear energy policy formulations and issuances.

There are several limitations in this paper: (1) Our proposed policy instrument identification method requires a great amount of expert knowledge in a specific policy domain. (2) This method requires a large amount of accessible policy text data, which makes it difficult for analyzing new and/or minor policy themes. (3) This method attempts to incorporate the structural holes theory in a policy system, but more case studies are required to verify the scientific and practical value of applying this theory.

We anticipate future studies in two distinct but related directions: (1) Develop ways to automate the identification of policy instruments in policy documents; (2) Construct more heterogeneous policy networks that contain policy targets, policy instruments and related policy institutions, in order to better reflect other real-world policy systems.

Author contributions

Cui Huang: Conceived and designed the analysis; Contributed data or analysis tools; Wrote the paper.

Chao Yang: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Jun Su: Conceived and designed the analysis.

CRediT authorship contribution statement

Cui Huang: Conceptualization, Investigation, Resources, Data curation, Writing - review & editing, Supervision. **Chao Yang:** Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Jun Su:** Supervision, Resources, Writing - review & editing, Project administration.

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