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SYNERGISTIC EFFECT ANALYSIS OF POLICY INSTRUMENTS IN ENVIRONMENTAL GOVERNANCE CONSIDERING THE SOCIAL CONTEXT

This article assess the synergistic effects between policy instrument combinations and social contexts in the field of environmental governance in 29 province-level regions in China, from 2006 to 2018.

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Synergistic effect analysis of policy instruments in environmental governance considering the social context

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Abstract: Identifying the effective pathways and policy effects of environmental governance under the carbon neutrality goal is the scientific basis for realizing the green and low-carbon transformation of the economy and society. At present, there is a lack of research on the effectiveness of environmental policy instruments from the perspective of synergistic effects, especially the similarities and differences in the use of policy instruments for pollution-control and carbon-abatement. By using fuzzy-set qualitative comparative analysis (fsQCA) and econometric regression model we take 29 provincial-level administrative regions in China as an example. In this paper we assess the synergistic effects between policy instruments and between policy instrument combinations and social contexts in the field of environmental governance in each province since 2006. Then an effective policy implementation pathway of instrument combination for environmental governance has been proposed. The study shows that: (1) Any combination of policy instruments is not a sufficient condition for high environmental performance, and sometimes they only serve as peripheral conditions to match the social context in which they are located to produce high governance performance. (2) For regions with low pollution severity and high innovation motivation, government does not need to consider the characteristics of the governance instrument itself as any instrument can achieve high performance. However, for regions with high pollution severity and low innovation motivation, the government's attitude towards environmental governance can affect the effectiveness of the policy instruments. When the determination of government governance is insufficient, regulatory instruments and information provision instruments play a leading role; on the contrary, more policy instruments (such as market instruments and technology adoption subsidy instruments), including innovation support instruments, should be used to achieve higher governance goals. (3) Although the feasibility of synergistic governance between pollution-control and carbon-abatement is high, the requirement for policy instruments still differs between the two. Finally, we use the econometric regression method to verify and expand the above conclusions and point out the similarities and differences between the fsQCA and econometric regression method in terms of variable explanation. This will provide empirical support for expanding the theoretical analysis of environmental governance methods.

Keywords: environmental governance; social context; policy instruments combination; synergistic effect; fsQCA; econometric regression analysis

1. Introduction

A key insight of modern public policy research is that solving complex policy problems usually requires an effective combination of policy instruments, i.e., a bundle of different policy instruments (Howlett & del Rio, 2015) which share a common goal (Kern & Howlett, 2009) and ideally the instruments are complementary or synergistic with each other (Howlett & Rayner, 2018). In recent years, policymakers have come to recognize the necessity of addressing environmental issues through the lens of a combination of policy instruments (Kern et al., 2019; Morrison et al., 2020). In its report on addressing social challenges such as the climate crisis, the OECD (2015) notes that policy instrument combinations play an important role in addressing a series of market failures. Although a large body of environmental governance research argues for the need for policy instruments combinations to address complex policy challenges (Schmidt & Sewerin, 2019; Capano & Howlett, 2020), most of the existing research rests on conceptual definitions and abstract classifications of policy instruments interactions (Schmidt & Sewerin, 2019); some scholars assess qualitatively through individual cases (Kern & Howlett, 2009; Rogge & Reichardt, 2016), but the generalizability of individual case study findings is relatively weak. Trencher et al. (2019) are among the first studies that moved from individual case studies to small-scale case comparisons, representing an important development; however, due to the complexity of the interactions between policy instruments, they can only analyze the interactions between two or three policy instruments. Therefore, there is a great lack of comparative analysis methods for policy instrument combination studies that are applicable to large samples of cases with multi-instrument combination experiences (Sewerin, 2020).

Second, due to different presuppositions, the available studies hold different views on the effectiveness of policy instruments combinations. Some studies have argued that market failures may undermine the effectiveness of a single environmental policy instrument and therefore a combination of instruments is the ideal choice (Johnstone, 2002; Fischer & Newell (2004); some studies have considered the complexity of multiple policy instruments combinations and argued that policy instruments may hinder or undermine each other (Howlett et al. 2015; Lesnikowski et al. 2019). For example, using government tax credits for enterprises that adopt end-of-pipe abatement technologies, which may distract enterprises from other pollution prevention strategies (e.g., environmental management systems), have been advocated by governments (Gunningham et al.). These studies have important implications for our understanding of the synergistic effects between different policy instruments. However, existing studies often do not distinguish the importance of various policy instruments and their interrelationships with each other, such as indicating which instruments play a central (peripheral) role in producing a certain outcome and which instruments are necessary (sufficient) conditions for a certain outcome.

Therefore, how to further analyze the interrelationships among policy instruments in synergy to be compatible with more evaluation dimensions has great academic value and practical significance for constructing a policy instrument combination research system.

In addition, one of the characteristics of most policy instruments combination studies is that they focus more on the content of the combination and less on the implementation context of the policy instruments combination. The existing policy research suggests that the impact of a combination of policy instruments depends not only on the content design but also on the policy implementation setting, which is an important factor. And the implementation setting is not external to the policy instruments but part of them (McLaughlin, 1987; Borrás & Edquist, 2013;

Reichardt et al. 2017). Mavrot et al. (2019) provide a case for researching the implementation setting of policy instruments combinations and they argue that focusing on the specific setting in which an intervention is implemented allows for a more accurate understanding of policy formulation goals and policy implementation effects; whereas target groups are included in policy instrument combinations because the recipient side of the policy may be as important as the sender side of the policy. However, the research also only conceptualizes the relationship between the social context and policy implementation effects in a specific case, without giving the specific components of the policy implementation setting and the way that it interacts with the policy instruments, thus limiting the broad applicability of the research framework.

To tackle the above shortcomings, the innovations of this paper are as follows.

(1) Unlike previous studies that only analyze the synergistic relationship between environmental governance instruments, this paper proposes a research framework for environmental governance that includes both policy instruments and social contextual factors. Although Peters (2007) proposed general social contextual factors that influence the potential implementation effects of policy instruments in the revised instrumental theory, he did not illuminate the synergistic relationship between policy instrument characteristics and policy setting factors. To fill this gap, we connect the government instrument analysis framework proposed by Salamon (2002) with the modified instrument theory proposed by Peters (2007) that considers the environment in which the instrument is located into a whole and analyze the implementation characteristics of environmental governance instruments while investigating the influence of the social context on the selection and implementation effectiveness of policy instruments.

(2) This paper provides a new way to investigate the synergistic relationship among policy instruments by Integrating QCA method and econometric regression method. We do not directly employ regression analysis to explain the relationship between variables as most previous studies do because these methods are limited in their capacity to deal with causally ambiguous scenarios (situations of causal ambiguity, e.g., multivariate synergistic relationships) or to explore the mechanisms of theory formation (e.g., interactions among more than three variables are often difficult to explain). In contrast, the fsQCA approach is based on set theory and uses Boolean algebra to minimize data for cases. It allows the induction of the characteristics of the conditions that lead to a given outcome and their synergistic relationships and thus construct new theories without being based on any assumptions (Greckhamer et al., 2008; Rubinson 2013). However, the disadvantage is that the approach lacks the capacity to quantify solutions. Based on the above considerations, by combining the fsQCA method with classical regression analysis, and by using a combination of QCA and classical regression models, we not only discover complex policy condition synergistic relationships, but also test and quantify these multi-factor complex synergistic effects. This process has not been previously explored by using statistical analysis alone and it will further strengthen our theoretical contribution.

Based on nearly 3,000 provincial-level environmental governance policy documents and annual policy setting data in the industrial sector in China from 2006-2018, we analyze the effects of a combination of policy instruments in different policy settings through a large sample of cases. We find that: (1) no stand-alone policy instrument or social contextual factors are necessary conditions for good environmental governance performance; and they need to be combined to form sufficient conditions for good environmental governance performance. (2) For pollution control, there are five high performance policy implementation pathways. (3) For carbon emission governance, although most of the pathways of high pollution reduction are also applicable to carbon reduction, however more attention should be paid to the use of market instruments and innovation support instruments in good carbon-abatement performance to avoid carbon emission spillover from regulatory, technology adoption subsidy and information provision instruments. Finally, we apply an econometric regression model to verify and quantify the solutions proposed by QCA for further consolidating the findings of this paper.

The remainder of the article is organized as follows: Chapter 2 provides a research review; Chapter 3 presents the research methodology and data; Chapter 4 presents the empirical findings; and Chapter 5 conclusion and policy recommendations.

2. Literature review

2.1 Synergistic effects of environmental policy instruments

Governments can use a variety of policy instruments to encourage industry to reduce emissions. Common policy instruments include regulatory and management measures, pricing of emission rights (including emission taxes, fees and tradable permits), subsidies for technological improvements, tax credits, industry information collection, and provision of technical information (the appendix provides a general definition of each instrument and its effectiveness in reducing emissions). Some combinations of instruments have been found to be more effective than the use of individual instruments (Stern, 1999; Nyborg et al., 2006; Stiglitz, 2019). For example, supervisory and regulatory instruments are effective in reducing industrial emissions, but in the short term it discourages enterprises from developing low-carbon technologies, so governments need to provide additional R&D subsidies to encourage enterprises to undertake expensive but promising technological innovations (Way et al., 2019). Emissions pricing alone can get rid of (fossil fuel) lock-in, but this can be achieved at a much lower cost when combined with regulatory and supervisory instruments (e.g., setting technology standards) (Mercure et al., 2014). Technology adoption subsidies can also be used as a complementary instrument for pricing emission rights. Technology adoption subsidies create niche markets for high-cost technologies and low-carbon products. It stimulates the expansion of related productive capacity, which in turn creates scale and learning effects. Eventually greater emission reductions will be achieved (Hoppmann et al., 2013). Furthermore, various meta-analyses suggest that information instruments itself do not have a strong abatement effect (Andor and Fels, 2018; Delmas et al., 2013; Wynes et al., 2018), but it can complement other kinds of instruments, thus creating positive synergies (Abrahamse & Steg, 2013; Schubert, 2017). For example, a combination of regulatory oversight or emissions pricing and information provision may be more effective than using one of these instruments alone (Nyborg et al., 2006; Stern, 1999; Stiglitz, 2019), because information provision helps policy target groups to respond to policy instruments such as emissions pricing, subsidies, etc. better (Lehmann, 2012).

2.2 Impact of social context on the effectiveness of policy instruments

For effective policy instruments (combinations) to be fully applied, the government needs to consider the prevailing social contextual factors together. This is because the effectiveness of the instruments is influenced by the environment in which they are placed (Peters, 2007; Boni et al., 2019; Zabala, 2021). Consequently, this paper incorporates the policy setting into the policy instrument combination research framework, i.e., policy instruments are most effective when they match the three policy setting dimensions of problem, goals, and target group, which are interrelated and irreplaceable (Peters, 2007). Further, the three social context dimensions proposed by Peters (2007) are conceptual formulations applicable to all public governance domains, while in this paper we focus on the environmental governance domain. Based on the existing literature on the implementation settings of policy instruments in the environmental governance domain, we correspond the above three dimensions to three specific manifestations of the domain - the current state of environmental problems, environmental governance goals, and the motivation of policy target groups in environmental governance. In the next section, we provide an overview of the existing literature on the interaction between policy instruments and policy contexts in environmental governance.

First, there are some differences in utilities of policy instruments for different degrees of environmental problems. When environmental problems are more severe, regulatory and management instruments can achieve highly effective environmental outcomes for governments, but they may perform poorly in inducing innovation and technological change (Jaffe et al., 2003; Sterner, 2003), since enterprises are unwilling to develop more efficient technologies fearing that standards may be tightened again (Harrington et al, 2004). On the contrary, when environmental problems are less severe, governments seek alternative instruments to achieve environmental improvements, such as tradable permits, subsidies and tax relief, R&D support, and other policy instruments. They allow target groups to retain freedom of choice and provide room for innovation, but there is usually greater uncertainty about the outcome. In response, governments employ regulatory instruments as reinforcements to avoid the emergence of unproductive entrepreneurs (Keohane et al., 1998; Christopher et al., 2019).

Second, goal-oriented governance processes have a central dimension in dealing with complex or critical public problems (Latham and Locke, 2006; Claudia, 2021). Acciai (2021) notes that policy goals and instruments are never neutral, i.e., the selection of an instrument may be influenced by the goal and its potential may depend on the guiding signals coming from governance goal setting. However, many studies point out a distinct gap between current local government governance goals and practice (Bulkeley and Betsill, 2013; Van der Heijden, 2019; Hege et.al., 2021). In China, for example, under the influence of political promotion and the fiscal decentralization system, some local governments prioritize economic development, and environmental goals often give way to economic targets. The result will be low efficiency or even ineffectiveness of environmental policy instruments. In addition, when setting policy goals, the government should also consider other social contextual factors to achieve emission reduction goals at the lowest possible administrative cost. For instance, if local enterprises have a high incentive to innovate and are more receptive to environmental policies, then the government can consider adopting less costly market-based instruments (e.g., emission pricing) or information instruments to achieve higher environmental goals.

Finally, the motivation of the target group is also an important factor that affects the effectiveness of the implementation of policy instruments. The intensity of enterprises' investment in innovation best reflects their dynamism (Yang, Xuzhi, and Li, Pazhou, 2007; Alam et al., 2019). In environmental governance, enterprises that are highly innovative are not only more likely to agree with government-implemented environmental governance policies. They are also less likely to confront or rent-seek from the government, and to take fuller advantage of the financial or technological facilities provided by the government. Thus, entrepreneurial technological innovation can be a prerequisite for policy instruments to be fully effective (Wesley, 1978). In addition, environmental policy instruments are also a prerequisite for enterprises to develop technological innovation. Examples of this include tax relief, broadening access to financing, and establishing innovation investment funds for innovative environmental enterprises to ensure a smooth transition from R&D demonstrations to commercialization and eventual adoption and use by other polluters of environmental technologies.

In summary, existing research have mainly analyzed the synergistic effects of two instruments, or the effects of individual environmental factors on the effectiveness of policy instruments but have not considered the interrelationships between all instruments and social contextual factors together. This means that the true effectiveness of policy instruments in the complex synergistic relationship of multiple factors is still unknown. As a result, in this paper we place environmental governance instruments and the social context in which they are located (environmental problem severity, government environmental goals, and target group) in the same framework to explore effective policy implementation paths in industrial emission reduction of China.

3. Research Methods

Necessary causality and sufficient causality are two emerging explanations of causal relationship. In this paper we use the fsQCA method to explore the necessary and sufficient causality between policy instruments and environmental governance performance. fsQCA takes a holistic perspective, conducts a cross-case comparative analysis, and explores which combinations of conditional elements will lead to the expected results (Ragin, 2008; Du Yunzhou, 2020). The fsQCA method mainly has the following characteristics: (1) it can determine how multiple variables are configured in different ways and thus influence performance; (2) it can assess whether multiple configurations are associated with the same outcomes; (3) it can test whether the presence or absence of any variable affects the role of the overall configuration (Jiang et al., 2021; Fiss, 2011; Misangyi et al, 2017; Ragin, 2008); (4) it combines the advantages of qualitative analysis and quantitative analysis for responding to questions about the generalizability of qualitative analysis in a few cases. Also, it compensates to some extent for the inadequacy of large sample analysis in qualitative change and phenomenon analysis. In addition, unlike traditional regression methods, fsQCA uses Boolean algebra which will not lead to omitted variable bias. Therefore, there is no requirement for control variables in the fsQCA method (Fainshmidt et al., 2020). In this study, the environmental effects are influenced by the social context and the policy instruments, and the configuration logic of fsQCA can be used to explain the variation in the performance of the policy instrument portfolio under different social contexts.

3.1 Variable definitions and data sources

(1) Environmental governance performance. Environmental governance performance is generally measured by the intensity of industrial pollutants or carbon emissions per unit of industrial added value. This measure can only reflect the current state of emissions from local industrial enterprises, but it cannot reflect the marginal improvement in local emissions compared to the previous year. It also ignores situations where the government slows down or damages the economy to meet environmental governance goal. A more reasonable measure is the degree of decoupling between air pollutants or carbon emissions and economic development. That is, when economic growth, the growth rate of pollutants or carbon emissions are negative or less than the economic growth rate, which is the real effective governance (Tapio，2005; Li, Yining et al. 2017). Accordingly, based on the Tapio decoupling theory, we use the ratio of the rate of change of industrial SO_2 emissions to the rate of change of industrial added value to measure provincial pollution-control performance. And we use the ratio of the rate of change of industrial carbon emissions to the rate of change of industrial added value to measure the provincial carbon-abatement performance. According to decoupling theory, the degree of decoupling between emissions and economic growth can be classified into eight types - expansive negative decoupling, weak decoupling, strong decoupling, expansive coupling, strong negative decoupling, weak negative decoupling, recessive decoupling, and recessive coupling. As the latter four types represent environmental governance performance during the economic recession and do not meet the long-term development goals of various regions, only the first four types are considered in this study (as shown in Table 1). The data of pollution emissions and carbon emissions of each province are taken from *the China Environmental Statistics Yearbook (2006-2020)*, and the data of industrial added value are taken from *the China Industrial Statistics Yearbook.*

Table 1 Definition of decoupling types

Type of decoupling	The Change of energy consumption or Sulphur dioxide emissions	The Change of industrial added value	Decoupling elasticity values	Definition
expansive negative decoupling	>0	>0	$\varepsilon > 1.2$	Economic growth at the cost of accelerating environmental damage.
expansive coupling	>0	>0	$0.8<\varepsilon<1.2$	Environmental pressure and economic growth are growing at the same time, and the rate of change is comparable.
Weak decoupling	>0	>0	$0<\varepsilon<0.8$	The rate of change of energy consumption or pollutant emissions increases at a slower rate than the economic growth.
Strong decoupling	<0	>0	$\varepsilon<0$	Ideally, economic will grow while the environmental pressure is relieved.

(2) **Policy instrument preferences**. Based on the magic weapon database of Peking University[1], this paper sets keywords which associate with the environmental governance goals such as "energy saving", "emission reduction", "carbon dioxide", "emission", and collects nearly 3,000 policies from 31 provinces, municipalities, and autonomous regions across China from 2005 to 2020. Existing research (Gupta et al., 2007;) divides the instruments in the field of environmental governance into regulations, taxes and charges, tradable permits, subsidies and incentives, research, and development (R&D) and information instrument, etc. However, this classification has two drawbacks. First, the boundaries between instruments are vague, such as subsidies and incentives and R&D. The former includes subsidies for R&D. Second, instruments with the same mechanism are separated. For example, taxes and charges and tradable permits are two different ways to price emissions with the aim of internalizing environmental externalities through market mechanisms. Therefore, we adjust the classification of environmental governance instruments to distinguish the characteristics of different instruments. We combine taxes and

[1] The magic weapon database of Peking University has included all the policies and regulations issued by Chinese government departments at all levels since 1949.

charges and tradable permits into market instrument and specify subsidies and incentives as subsidies for technology adoption rather than R&D. Then we can examine the government's efforts in environmental technology promotion and innovation incentives respectively. The adjusted policy instruments are shown in Table 2 and it comprises regulatory instrument, market instrument, technology adoption subsidy instrument, innovation support instrument and information provision instrument. Despite the increased independence of the instrument categories, this categorization is still too broad to facilitate effective policy instrument extraction in our policy documents. Therefore, a description of the specific measures included in each type of instrument is needed. Salamon (2002) constructs a framework for the study of instruments that is widely used in the modern field of public governance research. He divided general public policy instruments into direct government, social regulation, economic regulation, public information, contracting, government grants, financing support and tax expenditures. He describes the specific governance measures contained in each type of policy instruments. Based on this, we compare the definition of environmental governance instruments with the instruments analysis framework proposed by Salamon (2002) and analyze the specific measures corresponding to each environmental governance instrument, so as to obtain standard of review for extracting governance instruments from policy documents (as shown in Table 2). To verify the rationality of the classification system of policy instruments, we randomly sample 500 policy documents from the policy documents to be reviewed for testing. We assigned these policy documents equally to 10 reviewers for the extraction of policy instruments. Then, we conducted three rounds of review among the reviewers, and after each round of review, all reviewers were invited to share their experience to enhance their understanding of the classification system and consistency in classification decisions. After determining that the policy instruments in these 500 policy documents are all found their way into the appropriate categories in the classification system, we listed the keywords used to screen each category of policy instruments based on these policy documents (as shown in Table 1). Then we used these keywords to identify all policy instruments contained in the remaining policy documents. Significantly, we filtered out those policy instruments that did not give specific implementation options. Finally, to examine the preference of provincial governments in choosing policy instruments, we summed up the policy instruments involved in all policies of a province in the same year. Then we obtained the annual number of each policy instrument, and calculated the proportion of various policy instruments in the province's total instruments of the year.

Table 2 Types, definition, and keywords for environmental policy instruments

Types	**Definition**	**Measures**	**Main keywords**
Regulatory instrument	An instrument for governments to use regulation and direct action to influence the environmental behaviour of market organizations and individuals in society to achieve governance goals.	**Social regulation:** Command and control measures **Economic regulation:** Production control Access control	Laws and regulations, administrative means, compulsion, law enforcement, production capacity, elimination of backwardness, relocation, approval.
Market instrument	The way in which the government indirectly influences the behavioural choices of actors through market mechanisms, changing	**Social regulation:** Emissions taxes Sewage charges	Emissions trading, carbon trading, carbon market, energy saving,

	production and consumption capacities through price levers, transforming the costs of environmental pollution from external to internal instruments.	Emissions trading	total energy consumption management, carbon sink trading voluntary emission reduction trading.
Technology adoption subsidy instrument	By providing financial incentives to enterprises that implement environmentally friendly technology modification, the government aims to stimulate the widespread adoption of environmentally friendly technologies throughout society.	Government funding Financing support Tax relief	Promotion, technical transition, Pollution prevention, investment mechanism, energy-saving services, Special funds
Innovation support instrument	Through economic incentives, the government encourages social groups to innovate technologies and social infrastructure that reduce emissions.	Government funding Financing support Tax relief	Innovation, research and development, capacity building, technological progress, independent research and development
Information provision instrument	The government provides the community with information on environmental technology modification or directions for environmental technology innovation, and guides target groups to carry out targeted pollution-control and carbon-abatement activities.	Public information： Information interventions Technology adoption subsidy	Environmental Technology Directory Innovative directional guidance

(3) **Social contexts**. According to Modified Instrumental Theory (Peters, 2007), the effects of policy instruments cannot be explained only by the instruments themselves but are also affected by the social contexts in which the instruments are placed—the current state of environmental problems, environmental governance goals, and the motivation of policy target groups in environmental governance. To distinguish them from natural environmental factors, we define them in terms of social contextual factors, the differing combinations of which represent different social contexts. First, we use Sulphur dioxide emissions and carbon emissions per unit of industrial added value to represent the current state of environmental problems and define this indicator in terms of problem severity (SE). When we define environmental governance performance, we illustrate the difference between emission intensity and degree of decoupling to avoid confusion between the two indicators. Second, we measure the provincial environmental governance goals by checking whether the environmental goals set by the provincial governments in each five-year plan[2] are higher, lower, or equal to the central government's goals, and use environmental goal priorities (PR) to define this indicator. Finally, we use R&D investment per unit of output value of industrial enterprises to indicate the willingness of enterprises (target group) to change traditional production methods and thus reflect their motivation to adapt to environmental changes and define this indicator in terms of enterprise innovation motivation (IN).

In addition, after excluding the Tibet Autonomous Region and special municipalities (Beijing,

[2] The five-year plan is a goal-oriented governance approach with Chinese characteristics. In 2006, the "Eleventh Five Year Plan" set up binding indicators for resources and environment for the first time. Provincial People's governments are responsible for environmental work in the region. The main environmental governance goals are divided into two parts: reduction of energy consumption per unit of GDP (%) and reduction of total emission of major pollutants (SO_2) (%).

Tianjin, Shanghai, and Chongqing) that lack emission data[3], we obtained an annual sample of 274 provinces as study cases.

3.2 Variable calibration

In traditional regression methods, variables are measured in terms of raw values or specific sample scales like sample-specific mean and standard deviation. fsQCA goes a step further and uses external criteria and/or distribution to calibrate variables and suggests that not all variables are significant (Fiss, 2011; Ragin, 2008). Calibration is a process of assigning cases with set membership scores (Schneider & Wagemann, 2012). The degree of membership is indicated by calibrating the raw data to a score between 0 and 1, with a score of 0 indicating fully out membership, a score of 1 indicating fully in membership, and a score of 0.5 being a crossover point. Referring to calibration methods used in previous fsQCA studies (Campbell et al., 2016; Crilly, 2011; Fiss, 2011; Judge et al., 2014) and our understanding of the data characteristics and underlying theory (Rihoux & Ragin, 2009), we used direct calibration (continuous measurement) [4]and indirect calibration (categorical measurements) to calibrate the variables.

Outcome variables include elasticity of industrial energy consumption and elasticity of industrial sulfur dioxide emissions. Combined with decoupling theory, we calibrate these two types of elasticity. As we do not consider the recession scenario, only the four types of decoupling under economic growth are calibrated (as shown in Table 1). In decoupling theory, elastic variables have a clear division and should therefore be treated as categorical variables, so we choose the four-value assignment method of indirect calibration for calibration (Ragin, 2008; Crilly, 2011; Jiang et.al, 2021). The calibration results are shown in Table 3. The expansive negative decoupling is calibrated to 0, the expansive coupling is calibrated to 0.33, the weak decoupling is calibrated to 0.67, and the strong decoupling is calibrated to 1.

The antecedent variables include five policy instrument variables (regulatory instrument, market instrument, technology adoption subsidy instrument, innovation support instrument and information provision instrument) and three social context variables (problem severity, environmental goal priorities and enterprise innovation motivation).

Policy instrument selection preference: As the variable is biased rather than normally distributed, we drew on the practice of Pappas et al. (2017), and based on the calculation of variable skewness, we use a direct calibration method to set appropriate thresholds for each policy instrument. (as shown in Table 3).

Problem severity: We calibrated this variable using the direct calibration method. As the variable is biased rather than normally distributed, we chose the appropriate threshold by calculating the skewness of the variable. After ranking all the values of this variable from small to large, the 20th percentile was chosen as the full non-membership anchor, the 80th percentile as the high full-membership anchor and the 50th percentile as the crossover point (as shown in Table 3).

[3] Due to the differences in government hierarchy and financial system between provinces and municipalities directly under the central government, there are differences in the division of regulatory responsibilities, environmental protection expenditure responsibilities, environmental protection taxes, etc., which ultimately have an impact on the implementation and effectiveness of policy instruments. Therefore, this paper does not include municipalities directly under the central government in the sample in order to ensure that the same policy instruments of the cases discussed have a more consistent implementation effect.

[4] The direct calibration method is to convert the original data into the metric of log odds. This measurement takes 0 as the center and has no upper or lower limit. Since the rule of controlling the fuzzy sets crossover makes it difficult to analyze cases with an membership score of 0.5, Ragin (2008) suggested avoiding using an accurate 0.5 membership score to analyze causal conditions. To achieve this, we refer to the method used by fiss (2011) and manually increase the fuzzy points by 0.001. Fiss (2011) did this without affecting the results and ensured that no cases are deleted from the fuzzy set analysis.

Environmental goal priorities: As this variable has similar data characteristics to the outcome variables, we also used the indirect calibration method. The specific settings are shown in Table 3.

Enterprise innovation motivation: We used the same calibration method as the problem severity variable and the specific settings are shown in Table 3.

Table 3 Measurement and calibration of outcome variables with antecedent variables

	Variables	**Measurement**	**Skewness**	**Calibration anchors**	**Calibration principles**
Outcome variables	Industrial pollution emission flexibility	$\frac{\Delta SO_{2_t}}{SO_{2_t}} \Big/ \frac{\Delta GDP_t}{GDP_t}$ Of which $\Delta SO_{2_t} = SO_{2_t} - SO_{2_{t-1}}$, $\Delta GDP_t = GDP_t - GDP_{t-1}$, SO_2 represents industrial SO2 emissions in each region, GDP represents industrial added value in each region, and t represents year t.	/	0, 0.33, 0.67, 1	Indirect calibration. For this study, only four cases were considered (expansive negative decoupling, weak decoupling, strong decoupling, and expansive coupling) and 20 samples were excluded for this purpose. The expansive negative decoupling is calibrated to 0, the expansive coupling is calibrated to 0.33, the weak decoupling is calibrated to 0.67, and the strong decoupling is calibrated to 1.
	Industrial carbon emissions Flexibility	$\frac{\Delta CO_{2t}}{CO_{2t}} \Big/ \frac{\Delta IVA_t}{IVA_t}$ Where $\Delta CO_{2t} = CO_{2t} - CO_{2t-1}$, $\Delta IVA_t = IVA_t - IVA_{t-1}$, CO_2 represents industrial carbon emissions in each region, *IVA* represents industrial added value in each region, and t represents year *t*.	/	0, 0.33, 0.67, 1	Indirect calibration. For this study, only four cases were considered (expansive negative decoupling, weak decoupling, strong decoupling, and expansive coupling) and 20 samples were excluded for this purpose. The expansive negative decoupling is calibrated to 0, the expansive coupling is calibrated to 0.33, the weak decoupling is calibrated to 0.67, and the strong decoupling is calibrated to 1.
Policy instrument	Regulatory instrument	Percentage of regulatory instruments out of the total number of instruments in the same year in each region.	1.03	0.21, 0.3301, 0.45	Direct calibration. Calibrate fully in membership to above the 90th percentile and fully out membership to below the 10th percentile, with the 50th percentile being the crossover point.
	Market instrument	Percentage of market instruments out of the total number of instruments in the same year in each region.	3.12	0, 0.001, 0.14	Direct calibration. Calibrate fully in membership to above the 80th percentile and fully out membership to below the 20th percentile, with the 50th percentile being the crossover point.
	Technology adoption subsidy instrument	Percentage of technology adoption subsidy instruments out of the total number of instruments in the same year in each region.	0.09	0, 0.2901, 0.5	Direct calibration. Calibrate fully in membership to above the 90th percentile and fully out membership to below the 10th percentile, with the 50th percentile being the crossover point.
	Innovation support instrument	Percentage of innovation support instruments out of the total number of instruments in the same year in each region.	2.00	0, 0.001, 0.125	Direct calibration. Calibrate fully in membership to above the 80th percentile and fully out membership to below the 20th percentile, with the 50th percentile being the crossover point.
	Information provision instrument	Percentage of information provision instruments out of the total number of instruments in the same year in each region.	2.51	0.09, 0.1701, 0.25	Direct calibration. Calibrate fully in membership to above the 80th percentile and fully out membership to below the 20th percentile, with the 50th percentile being the crossover point.
Policy envirommnt	Problem severity	The intensity of industrial Sulphur dioxide emissions in each region in the current year.	2.18	0, 0.001, 0.02	Direct calibration. Calibrate fully in membership to above the 80th percentile and fully out membership to below the 20th percentile, with the 50th percentile being the crossover point.
		The intensity of industrial carbon dioxide emissions in each region in the current year.	1.23	1.40, 2.4101, 3.97	Direct calibration. Calibrate fully in membership to above the 80th percentile and fully out membership to below the 20th percentile, with the 50th percentile being the crossover point.
	Environmental	A comparison of the governance	/	0, 0.33, 0.67, 1	Indirect calibration. There are five scores (2,

goal Priorities	goals set by local governments and the central government for carbon-abatement in the five-year plan. When the individual goal set by the local government are higher than that of central government, a score of 1 is given, 0.4 is given when they are equal to the central government's, and 0 is given when they are lower than the central government one (Notes, Appendix). The scores of individual goals are calculated separately and then added together to calculate the total score.			1.4, 1, 0.8, 0) in the original dataset. Considering China's political system and governance structure, this study considers a individual indicator equal to or lower than the national standard to reflect the lack of attention paid by local governments to the relevant governance, and therefore counts a score of 1.4 and a score of 1 as one case. A score of 2 is calibrated to 1, a score of 1.4 or 1 is calibrated to 0.67, a score of 0.8 is calibrated to 0.33, and a score of 0 is calibrated to 0.
Enterprise innovation motivation	Investment in R&D per unit of output value of industrial enterprises above a certain scale.	1.06	0.01, 0.021, 0.03	Direct calibration. Calibrate fully in membership to above the 90th percentile and fully out membership below the 10th percentile, with the 50th percentile being the crossover point.

3.3 Necessary and sufficient conditions (Analytical Procedures)

In this study we use fsQCA 3.0 programming tool to analyze the necessary and sufficient conditions for generating high environmental governance performance.

Analysis of necessary conditions: We started the analysis by testing whether any factor was a necessary condition to achieve high pollution-control performance and high carbon-abatement performance, respectively. A causal condition is called 'necessary' or 'almost always necessary' if the instances of the outcome (high performance) constitute a subset of the instances of the causal condition (Ragin, 2008). In line with Greckhamer (2011), we adopt an individual consistency score of 0.90 as the cut-off threshold.

Sufficiency analyses: An algorithm based on Boolean algebra is used to logically reduce the Truth Table rows to simplified combinations (Fiss, 2011). Details are supplemented in Appendix 1a and Appendix 1b. Consistency thresholds 0.75 for high-performance configurations are adopted. The frequency threshold is set at 2, which is a sound standard to ensure at least two representative cases for each configuration identified by fsQCA3.0 (Judge et al., 2014). Our configurational results are generated and reported in Figure 1 and Figure 2.

4. Results of the empirical analysis and discussion

4.1 Necessary conditions of high environmental governance performance

As shown in Table 4, none of the individual factors exceeds the threshold of 0.90. Therefore, there was no individual factor qualifying as a necessary condition for both outcomes; that is, none of the design elements can be individually claimed as the necessary condition to both outcomes.

Table 4 Testing necessary conditions of high environmental governance performance

Antecedent variables	High pollution-control performance	High carbon-abatement performance
	Consistency	Consistency
Policy instrument variables		
Regulatory instrument	0.503	0.567
~Regulatory	0.523	0.605

instrument		
Market instrument	0.473	0.502
~Market instrument	0.539	0.596
Technology adoption subsidy instruments	0.501	0.599
~ Technology adoption subsidy instruments	0.524	0.583
Innovation support instrument	0.447	0.504
~Innovation support instrument	0.564	0.582
Information provision instrument	0.509	0.578
~Information Provision instrument	0.512	0.590
social context variables		
Problem severity	0.466	0.535
~Problem severity	0.561	0.618
Environmental goal priorities	0.454	0.455
~Environmental goal priorities	0.766	0.785
Enterprise innovation motivation	0.510	0.572
~Enterprise innovation motivation	0.507	0.593

4.2 Sufficient conditions of high environmental governance performance

We have used the same programming tool to analyze the sufficient conditions of generating high pollution-control performance and high carbon-abatement performance[5], and the results are shown in Figures 1 and 2. The radius represents the different pathways to high environmental governance performance, and the points on the radius are represented by five policy instruments (regulatory instrument, market instrument, technology adoption subsidy instrument, innovation support instrument, and information provision instrument) and three social contextual factors (problem severity, environmental goal priorities and environmental innovation motivations).

[5] Since 2010, sulfur dioxide emissions in most provinces have been gradually decoupled from economic growth. In this case, the number of samples with low pollution-control performance is small and meaningful empirical results cannot be obtained. Therefore, we do not list them here.

Among them, ● indicates the presence of core condition; ⊗ indicates the absence of core condition; • indicates the presence of peripheral condition; ⊗ indicates the absence of peripheral condition; and Blank space indicates that the condition is optional and redundant. QCA defines core conditions as those with strong causal relationship with the result, while peripheral conditions are those with weak causal relationship with the result. Two fit indicators, solution consistency and coverage, are reported in Appendix 2 and Appendix 3. These aid the better interpretation of results (Greckhamer, 2011; Ragin, 2008). The consistency score measures how well the solution corresponds to the data (Crilly, 2011; Ragin, 2008), which is calculated for each configuration separately as well as for the whole solution. Although consistency should be as close to 1 as possible to suggest that a subset relationship exists—that is, all cases (assuming equal to 1) would share a condition and the outcome—existing studies generally suggest an acceptable consistency level of 0.80 (Crilly, 2011; Fiss, 2011; Greckhamer, 2011; Ragin, 2008). We obtain overall consistency values of 0.902 and 0.833 for two high-performances and low-performance outcomes, respectively, and the individual consistency scores of all six configurations are also greater than 0.80.

4.2.1 Analysis of policy implementation pathways for high pollution-control performance

Based on the sufficiency analysis given in Figure 1, we obtain eight first-order pathways (H1 - H8) regarding high pollution-control performance which have different core conditions. Under every first-order pathway, there are second-order pathways with the same core conditions but different peripheral conditions (Fiss, 2011). For example, H2a and H2b are second-order pathways under the first-order pathway H1[6]. The following is a detailed analysis of the policy implementation pathway of each high pollution-control performance.

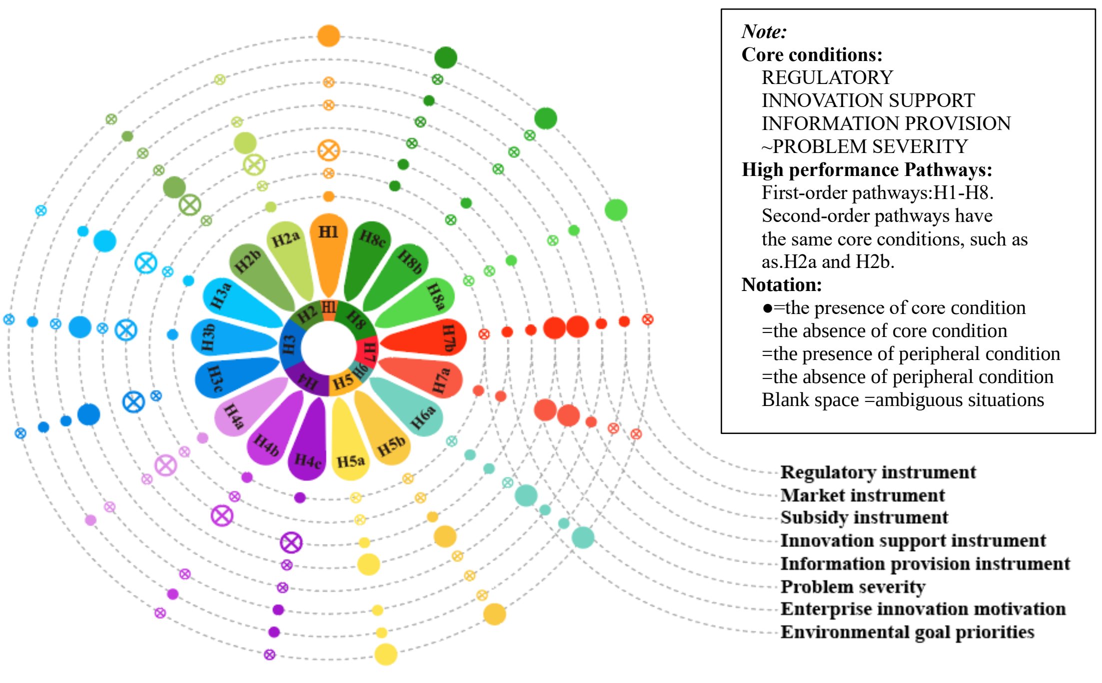

Figure 1 Policy implementation pathways for high pollution-control performance

6 The first-order pathway and the second-order pathway are defined by whether the core conditions are the same.

（1）Any type of individual policy instrument can produce high pollution-control performance in a low pollution social context

Figure 1 shows that in the policy pathways H1-H4, only one policy instrument is the core condition and the other policy instruments are peripheral or redundant conditions. Among the social contextual factors, low pollution severity is always the core condition, while government environmental goals and enterprise innovation motivation are only peripheral or redundant conditions. This suggests that high pollution-control performance can be generated by any type of policy instrument when the pollution problem is not high, such as regulatory instruments in H1, innovation support instruments in H2, information provision instruments in H3 and market instruments in H4. This is most likely because in regions with less severe pollution problems, where there is less resistance to policy implementation, the effectiveness of any policy instrument is not related to its own characteristics (coercion or channel of action), but is more like a governance signal from the government. In some scenarios, enterprises also have high innovation motivation to improve the environment, and the government can achieve high environmental governance performance by using any kind of instruments without publicizing the determination of pollution control to the public (high governance goals). There is no obvious difference in the effectiveness of various policy instruments in regions with low pollution severity.

（2）Regulatory instruments combined with information provision instruments are more effective in a social context with high pollution, low goals, and low innovation

In policy pathway H5, high regulatory instruments and high information provision instruments are core conditions and the other policy instruments are peripheral or redundant conditions. Among the social contextual factors, high pollution severity, low enterprise innovation motivation and low government environmental goals are all peripheral conditions. The governance instruments under this pathway present a distinctive feature in that innovation support instruments are always lacking or redundant. This is likely because the government's low environmental governance goals are insufficient to guide enterprises to carry out long-term and risky innovation activities for cleaner production. Enterprises are more willing to take some low-risk actions to meet government emission reduction requirements. The regulatory and information provision instruments represent the minimum standard of emission reduction and the minimum effort required, respectively, and are therefore the two most effective instruments in this context. H5b adds market instrument and technology adoption subsidy instrument to H5a, but also functions only as peripheral conditions. Overall, although the policy pathway H5 has alleviated the pollution problem to a certain extent, enterprises are relatively passive in pollution control and lack the motivation to improve their production methods independently.

（3）Regulatory instruments combined with innovation support instruments are more effective in a social context with high pollution, high goals, and low innovation

In policy pathway H6, high regulatory instrument and high innovation support instruments are core conditions, and match with high market instruments and high technology adoption subsidy instruments. Among the social contextual factors, high pollution severity, low enterprise innovation motivation and high government environmental goals are all peripheral conditions. Faced with serious pollution problems, the government still sets high environmental goals for industrial enterprises with low innovation motivation. Obviously, the government’s environmental governance is more difficult in this scenario. On the one hand, mandatory instruments (such as regulatory instruments) are needed to put pressure on polluting enterprises, and on the other hand, far-sighted policy instruments (such as innovation support instruments) are needed to reshape polluting enterprises' production methods and incentivize them to make long-term development strategy for the transformation of cleaner production. In addition, market instruments and technology adoption subsidy instruments can reduce the burden of environmental protection costs for enterprises, providing a viable transition for the clean transition.

(4) Innovation support instruments combined with information provision instruments is more effective in a social context led by high goals

In policy pathway H7, high innovation support instruments and high information provision instruments are core conditions and the other policy instruments are peripheral conditions. Among the social contextual factors, the high environmental goal is always a peripheral condition, while the other two social contextual factors are peripheral or redundant conditions. In H7a, regardless of the severity of the pollution problem, a high-goal government can promote high-innovation enterprises to achieve high environmental governance performance through innovation support, information provision, and technology adoption subsidy instrument. In H7b, in addition to high environmental goal, high pollution severity and low enterprise innovation motivation also become peripheral conditions, and high market instruments are added as peripheral conditions. This suggests that in regions with high pollution and low enterprise innovation motivation, policy instruments related to innovation support alone do not provide incentives for such enterprise to undertake pollution control, and that market instruments, such as emissions taxes, sewage charge or emissions trading, are needed to guide and constrain enterprise behaviour.

(5) Regulatory instruments are more effective in a social context with high pollution

In policy pathway H8, high regulatory instruments are always core conditions, high pollution severity is always a peripheral condition, and the other instruments or environmental factors are peripheral or redundant conditions. In contrast to H5 and H6, only high pollution severity is explicit in the contextual factors for H8, and the other two conditions are not explicit. In this scenario, only the regulatory instrument is the core condition among the policy instruments, and the occurrence of other instruments is not fixed, which means that the applicable scenarios of the regulatory instrument may be broader and more effective than other policy instruments.

Overall, these implementation pathways have 3 common characteristics: (1) Each type of policy instrument cannot produce high pollution-control performance consistently, and policy instruments always work within a certain social context. Sometimes the policy instrument does not even function as a core condition (as shown in H4). This suggests that no policy instrument (combination) can produce high pollution-control performance independently from the social context. Likewise, without policy instruments, social contextual factors (such as through enterprise innovation or government announcements of environmental goals to the public) cannot autonomously generate high environmental governance performance. (2) In the social context, only low problem severity is the core condition, and other social contextual factors only appear as peripheral conditions. This suggests that provinces with less pollution are more likely to achieve decoupling of emissions. Furthermore, problem severity and innovation motivation tend to combine in opposite ways, that is, high problem severity is always combined with low innovation motivation or low problem severity with high innovation motivation. This shows that in provinces with serious industrial pollution, enterprises themselves are less motivated to innovate, and vice versa. In addition, the government's setting of environmental goals does not clearly match the other two social contextual factors, that is, provincial governments will not set lower environmental goals because of high pollution severity or low enterprise innovation motivation. (3) Among the pollution-control instruments, high regulatory, high innovation support or high information provision always play a role in core conditions, while market instruments and technology adoption subsidy instruments are only supplements to the above instrument. This reflects the feature of policy instruments in effective pollution control.

4.2.2 Analysis of policy implementation pathways for high carbon-abatement performance

Figure 2 shows the sufficient conditions for high carbon-abatement performance, and 10 first-order pathways S1-S10 regarding high carbon-abatement performance. Compared with the results in Figure 1, the policy implementation pathways of high carbon-abatement performance S1-S3 and S7-S9 can all find highly similar counterparts in the high pollution-control performance. This indicates that most of the synergistic relationships with high pollution-control performance between policy instruments and between policy instruments (combinations) and their environment are also highly applicable to carbon-abatement governance. It means that the feasibility of synergistic governance between pollution-control and carbon-abatement is high. However, there are also differences between carbon-abatement and pollution-control pathways.

First, the high carbon-abatement pathway has more requirements for the cooperation among policy instruments, and the number of policy instruments as the core condition is obviously more than that of the pollution-control pathway. In particular, when some policy instruments are heavily used in the pathway, the use of other policy instruments must be reduced. For example, the core conditions in S2 and S9 are high regulatory instruments and low information provision instruments, and in S3 the core conditions are high regulatory instruments and low technology adoption subsidy instruments, which means that regulatory instruments cannot be used in conjunction with information support instruments and technology adoption subsidy instruments. However, synergies between regulatory instruments and technology modification such as technology adoption subsidy, innovation support, and information provision instruments are common in high pollution-control pathways. It suggests that the two types of instruments can amplify each other's pollution-control effects, but do not lead to carbon-abatement. This is most likely because the pollution-control technologies adopted by polluting enterprises are generally energy-intensive, which will lead to more carbon emissions when reducing pollution. Taking coal power plants as an example, the most direct way to reduce pollution is to add high-energy equipment such as denitrification devices, electrostatic precipitators, and desulfurization systems. Reducing pollution without switching to cleaner energy sources will definitely increase carbon emissions, so the combined use of regulatory instruments and technology modification (technology adoption subsidy or information provision) may help to better achieve pollution-control goals. Nevertheless, it also causes a surge in carbon emissions due to the government's one-sided pursuit of pollution-control results.

Second, innovation support instruments offer more possibilities for carbon-abatement than technology modification. In S1, S8 and S10, the high innovation support instrument functions as the only core instrument, and in most cases the high technology adoption subsidy instrument or high information provision instrument is used in conjunction with it as a peripheral condition. This suggests that the innovation support instrument is more effective than the technology modification in carbon-abatement, and it can consider both pollution-control and carbon-abatement governance goals. Technology adoption subsidy and information provision instruments provide a niche for enterprise innovation and help enterprise to innovate and adopt more visionary technologies.

Third, the role of market instruments is considerably greater in the high carbon-abatement pathway compared to pollution-control pathway. In pathways S4, S5, S6 and S10, high market instruments emerge as core conditions and play an important role together with other instruments. This is because, whether regulatory or technology modification are applied to polluting enterprises, they are encouraged to meet the emission standards set by the government by reducing the pollution emission intensity. But this may lead to the spillover effect of carbon emissions. On the one hand, enterprises that meet the pollution intensity standards may compensate for the cost of emission reduction by increasing their output, which will eventually lead to an increase in total energy consumption, total pollution, and total carbon emissions. On the other hand, polluting enterprises cannot control the rise in total energy consumption and carbon emissions, although they can avoid the rise in total pollution caused by increased production through end-of-pipe emission control techniques. This 'carbon loophole' in high pollution-control performance can be filled by market instruments, such as carbon pricing instruments that can constrain the total carbon emissions of enterprises. It helps to reduce the carbon spillover from regulatory instruments and technology modification instruments, and enhance the effectiveness of the combination of policy instruments in carbon-abatement.

In addition, the above combination of policy instruments does not have a high requirement for the matching social context (the combination of contextual factors do not form a fixed match with the combination of policy instruments). Moreover, the policy instruments have a wider environmental applicability, which is not common in a high pollution-control pathway (except for regulatory instruments, all other instruments need to work in a specific social context). This is likely because, compared with pollution-control, carbon-abatement in various regions have a larger room for reduction, so there is currently a better response to any combination of policy instruments.

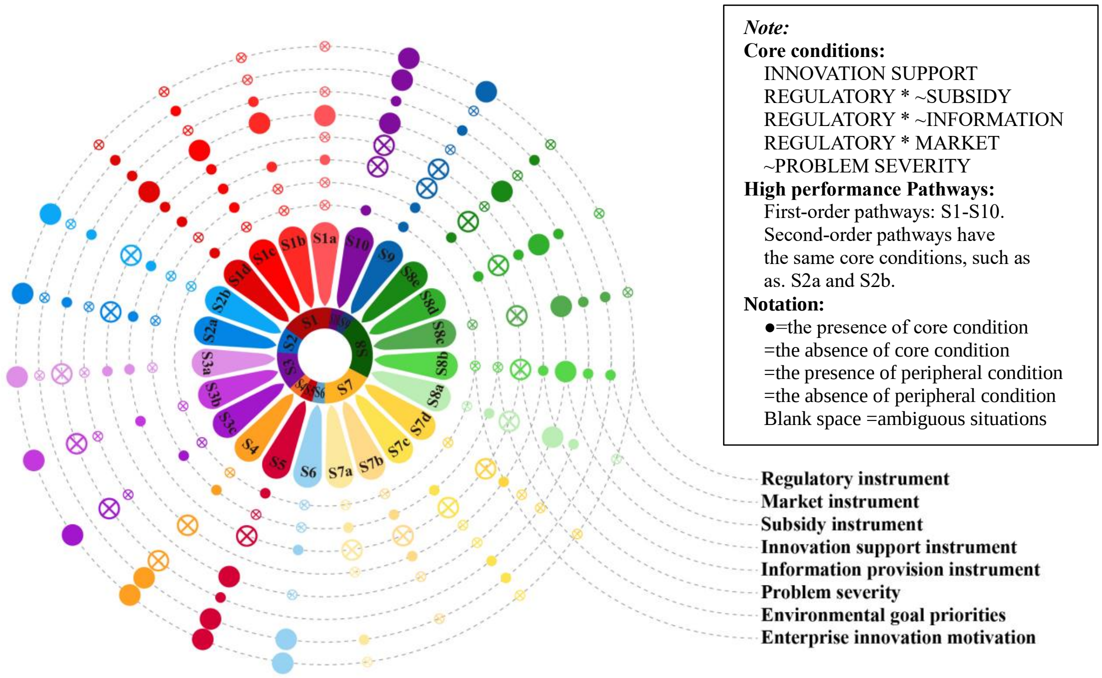

Figure 2 Policy implementation pathways for high carbon-abatement performance

4.3 Robustness test

To examine the stability of the results, we conducted robustness test. Following previous studies, we used two main types of robustness tests. First, we increased the frequency threshold and set the cut-off thresholds for the minimum number of cases to 3 and 4, respectively. It produced generally the same results (Supplementary Tables 4-7). Second, we increased the consistency level to 0.85 while keeping other settings unchanged. The results show that increasing the level of consistency leads to a small reduction in the number of configurations (Exhibits 8 and 9). In summary, our results are robust, and no meaningful bias was found.

5. Quantitative analysis of high environmental governance performance

Previously, we recognized the complex synergies between environmental governance instruments through the QCA method and generalized the core conditions and pathways that lead to high environmental governance performance. However, we were unable to quantify the extent to which these conditions and pathways would lead to high environmental governance performance. In addition, the QCA method does not incorporate the impact of temporal changes on environmental governance performance, but instead conducts a parallel comparative analysis of cases at different times (Caren et al., 2005; Vis et al., 2013; Fischer and Maggetti, 2017). To make up for the shortcomings of the QCA method and further test the reliability of the QCA results, we introduce an econometric regression model to quantify the net effect of the antecedent conditions (core and peripheral conditions) and the overall synergistic relationship (configuration) on environmental governance performance in each pathway obtained by QCA while controlling for time effects.

We used an OLS panel fixed effects regression model and fed the results of fsQCA into the regression model to determine the relative importance of different influencing factors. Drawing on Grant et al. (2010) and Kalleberg and Vaisey (2005), we set up separate regression models for each pathway (configuration). Then we took the antecedent condition and the fuzzy set score (ranging from 0 to 1) of the pathway as explanatory variables in the regression model, and the fuzzy set score of the outcome variables (ranging from 0 to 1) as the explained variable and we controlled for time effects. The fuzzy set score represents the degree of membership of a case on the condition or pathway. 0 represents fully out membership, 1 represents fully in membership, and a value between 0 and 1 represents the case falls between fully out membership and fully in membership. We illustrate the calculation of the fuzzy set score using the high carbon-abatement pathway S2a as an example. The configuration of path S2a is "high regulatory * low market * high technology adoption subsidy * low information provision * high problem severity * low innovation motivation * low government goal". According to the basic operative law of the Fuzzy sets, the fuzzy set score of this path = min [high regulatory, low market, high technology adoption subsidy, low information provision, high problem severity, low innovation motivation, low government goal], that is, the fuzzy set score for this path is defined as the minimum of the fuzzy set score of all the antecedent conditions belonging to this configuration. There are two core solutions for this pathway, high regulatory and high regulatory * low information provision. The former is equal to the fuzzy set score of high regulatory and the latter is equal to the minimum of high regulatory and low information provision.

In Appendix 10, we quantified the relative importance of main effects (antecedent conditions) and configurations (pathways) in all high pollution-control pathways. As can be seen in Figure 1, high regulatory, high innovation motivation, high information support and low problem severity are the four core conditions for high pollution-control performance. We found that the main effects of the regression results also show the same characteristics: regulatory, innovation support, information provision and market instruments have a significant positive effect on pollution-control performance, while the effect of information support is not significant, but its coefficient is always positive. Problem severity and government goal instruments have a significant negative effect on pollution-control performance, while the effect of innovation motivation is not significant, but its coefficient is always positive. Second, the regression results show the sequence of importance of policy instruments: technology adoption subsidy instrument > regulatory instrument > market instrument > innovation support instrument > information provision instrument. This reveals a difference between the QCA method and the econometric method in mining the characteristics of the sample. In fact, the most influential variable (such as the technology adoption subsidy instrument) is not necessarily the core condition. This is because the econometric regression method presupposes linear, additive, and one-tailed effects between variables. This precludes the possibility of examining non-linear, synergistic, and other final effects (Fiss 2007), so the result is a ranking of importance under a set of assumptions. The measurement results can reveal some of the effects of the variables but are not comprehensive. However, the QCA method extracts the most stable explanatory factor (core condition) through the set operations. This factor will not be affected by the presence or absence of other conditions, nor will it change because of the linear or nonlinear relationship between variables. Therefore, Although QCA cannot quantify the degree of influence of explanatory variables, it provides a way to find the most stable explanatory variables. Furthermore, the absolute value of the problem severity coefficient is larger than the coefficients of all policy instruments. The QCA results also show that low problem severity is a core condition. This further illustrates the importance of the current state of environmental problems in achieving high pollution-control performance. Provinces with low pollution severity are more likely to achieve sustained improvements. It also suggests that the earlier the environmental governance, the better would be the results. The last but not the least, the coefficient of the pathways reflects the effect of the overall policy plan composed of policy instruments and social contexts on pollution-control performance. Table 5 shows that most pathways (configurations) are significant, implying that following these policy pathways is effective in improving pollution-control performance. And those pathways that are not significant, is mainly because the number of cases that fit these pathways is too small[7] in the econometric regressions and therefore the coefficients for these configurations are not significant. However, the coefficients of these pathways are always positive, reflecting the effect of the overall policy plan on environmental governance.

We present the detailed regression results of high carbon-abatement pathways in Appendix 11. The results show that:

(1) Compared to the high pollution-control pathways, although the impact of policy instruments and social contextual factors on carbon-abatement is not significant, the sign of the

[7] QCA sets the minimum number of cases when extracting the pathway. The minimum number of cases set in this paper is 2, that is, if two or more cases conform to this pathway, the pathway will be displayed in the result (Figure 1).

coefficient is still consistent with the high pollution-control pathways. This again verifies our conclusion obtained in the QCA, that is, the high degree of synergy between pollution-control and carbon-abatement governance. In particular, market instruments remain highly effective in carbon-abatement governance and play a significantly positive role. The role of the social contextual factors of low problem severity is very robust and it reflects the current state of environmental problems which plays an important role in pollution-control and carbon-abatement.

(2) Compared to the high pollution-control pathways, the core conditions of the high carbon-abatement pathways are more complex. As shown in Figure 1, in addition to high innovation support and low problem severity, three other core conditions are composed of high regulatory * low technology adoption subsidy (Regulation*~Technology adoption subsidy), high regulatory * low information provision (Regulation*~ Information), and high regulatory * high market instruments (Regulation*Market) which the former two conditions are antecedent conditions. The regression results show that the core condition of high regulatory * low technology adoption subsidy has a significant positive effect on carbon-abatement, while the coefficients of high regulatory * low information provision and high regulatory * high market instruments are not significant but always positive. This result again verifies our judgment in 4.2.2 that the high carbon-abatement pathway has higher requirements for the combination of policy instruments, especially the combination of regulatory instruments and other instruments. Whereas regulatory instruments cannot be used in combination with technology adoption subsidy or information support instruments, a combination of regulatory and market instruments can help achieve high carbon-abatement performance.

(3) Compared to the high pollution-control pathways, we found that the significance of the regression results is not high in carbon-abatement pathways. This is because carbon emissions governance in China has only started in recent years. The cases of high carbon-abatement performance in the QCA results are far less than those with high pollution-control performance, but the number of high carbon-abatement pathways is more than that of high pollution-control pathways, so the number of cases included in each pathway is even smaller. And the econometric regression method needs to explore the effects of explanatory variables on the results with a sufficiently large sample size. Thus, it leads to a situation where most pathways are not significant. However, the coefficients for these configurations are still positive, reflecting the validity of the carbon-abatement pathways extracted by QCA to a certain extent.

6. Conclusions and policy recommendations

In this paper we proposed an analytical framework for exploring the effectiveness of combination of policy instruments in different social contexts. This framework consists of five environmental governance instruments with relatively independent operating mechanisms and three social contextual factors that affect the utility of the instruments. Under this framework, we analyzed the complex synergies between policy instruments and between instruments and contexts by using the diverse experiences of environmental governance in different regions of China as examples. We first used the fsQCA method to explore the complex synergistic relationship of multiple instruments that cannot be discovered by simple linear relationships, and qualitatively obtained policy instrument configuration plans with high environmental governance performance. Then we introduced the econometric regression model to test and quantify the above policy plans and obtain the following conclusions:

In terms of pollution governance, we have obtained five types of policy plans with high pollution-control performance: (1) policy plans using individual instrument under low pollution context; (2) policy plans using combination of instruments dominated by high regulatory and high information provision instruments under high pollution, low goal and low innovation context; (3) policy plans using combination of instruments dominated by high regulatory and high innovation support instruments under high pollution, high goal, low innovation context; (4) policy plans using combination of instruments dominated by high innovation support and high information provision instrument under high goal context; (5) policy plans using combination of instruments dominated by high regulatory instrument under high pollution context. The above policy plans share three common features. First, each type of policy instrument cannot produce high pollution-control performance on its own, and it needs to function within a certain social context. Sometimes policy instrument does not even act as a core condition, but only as a peripheral condition. Second, in the social context, government environmental goals and enterprise innovation motivation only appear as peripheral conditions, while low pollution severity is always a core condition in combination with a policy instrument to form a high-performance pathway. This suggests that compared with the first two social contextual factors, the current state of environmental problems is more conducive to the performance of policy instruments. Third, the combination of policy instruments in high pollution-control performance is often characterized by high regulatory, high innovation support or high information provision instruments as core conditions, while market and technology adoption subsidy instruments only complement these instruments.

In terms of carbon emissions governance, most policy implementation pathways with high pollution-control performance are equally effective in carbon-abatement, that is, the feasibility of synergistic governance between abatement and carbon-abatement is high, but high carbon-abatement performance requires a higher level of coordination between policy instruments. First, it is important to avoid using both regulatory instruments and technology modification, which can amplify each other's pollution-control effects but do not lead to carbon-abatement; Second, compared to technology modification, innovation support instruments can consider the two governance goals of pollution-control and carbon-abatement, which will help enterprises to innovate and adopt more visionary technologies. Third, compared to the high pollution-control pathway, the importance of market instruments in the high carbon-abatement pathway is significantly increased. The combination of market instruments and high regulatory instruments becomes a core condition which helps to make up for the carbon emission spillover effect caused by high regulatory instruments or high technology adoption subsidy instruments.

In addition, we used the regression results to verify the rationality and effectiveness of the pollution-control and carbon-abatement pathways extracted by QCA to a certain extent, which reflects the similarity between the QCA method and the econometric regression method. However, we also identified differences between the two methods in terms of empirical analysis. The ranking of the importance of policy instruments in regression results is not completely consistent with the results obtained by the QCA method. The most influential policy instrument in the regression results is not the core condition in the QCA results. We guess that this is due to a series of assumptions among variables in the regression model, which makes it impossible to include various forms of variables that may affect the outcome variables, so the regression results only obtain the importance order of variables under limited conditions. In other words, the QCA method uses the method of set operations to directly summarize the most stable factors (core conditions) in the combination of policy instruments that lead to high environmental governance performance, avoiding the impact on the net effect of variables due to prior assumptions about linear relationships between variables.

In response to the above conclusions, the policy recommendations that can be given are: First, when formulating environmental governance policy plans, the government should not only understand the intrinsic function of a specific instrument, but also recognize the effectiveness of a policy instrument. It should also consider the way in which instruments are combined with each other as it is influenced by a variety of social contextual factors. For regions with low pollution severity and high innovation motivation, government does not need to consider the characteristics of the governance instrument itself, as any instrument can achieve high performance. However, for regions with high pollution severity and low innovation motivation, the government's attitude towards environmental governance can affect the effectiveness of the policy instruments. If the government's determination to environmental governance is insufficient, enterprises are more inclined to respond to a combination of low-standard and low-cost policy instruments (such as regulatory instrument and information provision instrument). On the contrary, enterprises will further consider borrowing more policy instruments including innovation support instruments (such as market instruments and technology adoption subsidy instruments) to achieve a long-term and systematic clean low-carbon transformation. Second, for regions with high levels of both pollution and carbon emissions, the government should pay attention to the degree of synergy between policy instruments in addressing different types of environmental problems. Regulatory instruments, technology adoption subsidy instruments and information provision instruments are not sufficiently synergistic for the two environmental problems mentioned above. Although these policy instruments are very effective in pollution-control, they may lead to carbon emission spillover. Therefore, the government needs to strengthen the use of market instruments and innovation support instruments. Third, the government should pay attention to the development stage and characteristics of local environmental problems when designing environmental policies. In our case studies, most of the effective policy pathways occurred during the Eleventh Five-Year Plan and the Twelfth Five-Year Plan period. In these two periods, due to the large space for pollution-control and carbon-abatement, the government mainly focused on end-of-pipe governance and there are many combinations of policy instruments. However, since the 13th Five-Year Plan, end-of-pipe governance has reached a bottleneck, and the government needs to adjust the industrial structure and energy structure to achieve source governance and prevention. So, the use of innovation support instruments in combination with other instruments is particularly important in this period.

This paper still has the following shortcomings. First, when comparing environmental policy instruments, it is necessary to consider and adjust the strictness of different policy implementations. This paper only assumes that similar policy instruments have the same policy intensity from the perspective of the same administrative level, which simplifies the assessment of the issue of policy implementation intensity. Second, we only distinguish the types of policy instruments from a broad category. In fact, there are more detailed categories under each policy instrument, and their effects are not the same. For example, market instruments such as emissions taxes and tradable permits, although both of which put a price on pollution, have different mechanisms and targets in reality. Therefore, future research can discuss the differences between more subcategories of policy instruments in more details. Finally, due to the limitation of the sample size, we simplified the description of the social context, and selected three key social contextual factors (problems, goals, and target group) in the field of public governance in various countries for discussion, which to some extent reflects the generalizability of the findings of this paper to other countries. But in addition to these factors, there are many other factors that affect the effectiveness of policy instruments which together form a huge social network and affect the direction of policy effects. These are issues that still need to be explored.

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Appendix 1a. Truth table of configuration solutions leading to high pollution-control performance

Regulatory	Market	Adoption Subsidy	Innovation support	Information provision	Innovation Investment	pollution Severity	Goal Priority	number	Performance	raw consist.	PRI consist.	SYM consist
0	1	1	0	0	1	0	0	2	1	0.975	0.973	0.973
0	1	0	1	0	1	0	0	6	1	0.975	0.974	0.974
1	1	1	0	1	0	1	0	2	1	0.974	0.968	0.968
0	0	1	1	1	1	0	0	2	1	0.973	0.970	0.970
0	1	1	1	1	1	0	0	2	1	0.972	0.971	0.971
1	0	1	0	0	0	1	1	5	1	0.971	0.968	0.968
0	1	0	1	0	1	0	1	2	1	0.971	0.969	0.969
1	1	1	1	1	0	1	0	2	1	0.971	0.966	0.966
0	1	0	1	1	1	0	0	2	1	0.969	0.967	0.967
1	1	0	1	0	1	0	0	5	1	0.969	0.967	0.967
0	1	1	1	1	0	0	0	2	1	0.968	0.965	0.965
0	1	1	1	0	0	0	0	2	1	0.968	0.965	0.965
1	1	0	0	0	1	0	0	6	1	0.968	0.965	0.965
0	1	1	0	0	1	0	1	3	1	0.967	0.965	0.965
0	1	0	0	1	0	0	0	2	1	0.966	0.958	0.958
1	1	1	0	0	0	1	0	2	1	0.965	0.958	0.958
1	1	0	0	1	0	1	0	2	1	0.964	0.952	0.952
0	1	0	0	1	0	1	0	2	1	0.964	0.954	0.954
1	0	1	1	0	0	1	0	2	1	0.963	0.956	0.956
0	0	1	1	1	1	1	1	2	1	0.962	0.957	0.957
1	0	1	0	1	1	0	0	2	1	0.961	0.957	0.957
1	1	1	1	0	0	1	1	4	1	0.959	0.952	0.958

0	1	1	1	0	0	1	0	2	1	0.957	0.952	0.952
1	1	1	1	0	1	0	1	2	1	0.954	0.950	0.950
0	1	1	1	1	1	0	1	3	1	0.954	0.950	0.961
1	0	0	0	0	1	0	0	3	1	0.952	0.948	0.948
1	1	0	0	1	1	0	0	4	1	0.951	0.946	0.946
1	0	1	0	1	1	1	0	2	1	0.951	0.944	0.944
0	0	1	1	0	1	0	0	2	1	0.950	0.946	0.946
0	1	0	0	1	1	0	0	3	1	0.938	0.932	0.932
0	0	1	0	1	0	1	0	4	1	0.932	0.918	0.918
0	0	0	1	0	0	1	0	3	1	0.932	0.916	0.916
1	0	0	0	0	1	1	0	3	1	0.929	0.919	0.919
1	0	0	0	1	1	0	0	6	1	0.926	0.921	0.921
0	1	1	1	0	1	0	0	3	1	0.916	0.911	0.911
1	0	1	0	0	0	1	0	4	1	0.916	0.905	0.905
0	0	1	1	0	0	1	0	2	1	0.916	0.897	0.897
0	0	0	1	1	0	1	0	2	1	0.910	0.888	0.888
0	0	1	0	1	1	0	0	3	1	0.906	0.897	0.897
0	1	0	0	0	1	0	0	3	1	0.906	0.896	0.896
1	0	1	0	1	0	1	0	3	1	0.902	0.882	0.901
1	0	1	0	0	1	1	1	2	1	0.899	0.883	0.884
1	0	0	0	1	0	0	0	2	1	0.897	0.880	0.880
0	1	1	1	1	0	1	1	3	1	0.895	0.886	0.886
0	1	0	1	0	0	1	0	4	1	0.893	0.877	0.896
0	0	1	1	1	1	0	1	2	1	0.887	0.874	0.874
1	0	0	0	1	1	1	0	2	1	0.887	0.868	0.868
1	0	0	0	0	0	1	0	6	1	0.885	0.866	0.866

0	0	0	0	1	1	0	0	3	1	0.880	0.870	0.870
0	0	0	0	1	0	1	0	6	1	0.866	0.828	0.835
0	0	1	1	1	0	1	0	3	1	0.863	0.830	0.830
1	0	0	0	1	0	1	0	2	1	0.861	0.817	0.817
1	0	0	0	1	0	1	1	2	0	0.829	0.776	0.822
0	0	0	0	0	0	1	0	3	0	0.815	0.778	0.778

Appendix 1b. Truth table of configuration solutions leading to high carbon-abatement performance

Regulatory	Market	Adoption Subsidy	Innovation support	Information provision	Innovation Investment	pollution Severity	Goal Priority	number	Performance	raw consist.	PRI consist.	SYM consist
0	1	1	0	0	1	0	0	2	1	0.961	0.879	0.879
0	1	0	0	0	1	0	0	2	1	0.947	0.825	0.825
1	1	1	1	0	0	0	1	2	1	0.939	0.770	0.770
1	1	1	1	0	1	0	1	2	1	0.940	0.769	0.769
1	1	1	0	0	0	1	0	2	1	0.955	0.763	0.763
1	1	1	0	1	0	1	0	2	1	0.941	0.757	0.761
0	0	0	1	0	0	1	0	2	1	0.935	0.748	0.748
0	0	1	1	0	0	1	0	2	1	0.946	0.735	0.751
1	0	1	0	0	0	1	1	5	1	0.920	0.733	0.863
0	0	1	1	1	1	0	1	3	1	0.926	0.728	0.728
0	1	0	1	0	1	0	0	7	1	0.890	0.723	0.723
1	1	0	0	0	0	1	0	2	1	0.931	0.707	0.723
0	0	1	1	0	1	0	0	2	1	0.936	0.700	0.756
0	0	1	1	1	1	0	0	2	1	0.940	0.692	0.692

1	0	1	0	0	1	0	1	2	1	0.929	0.691	0.809
1	1	0	0	0	1	1	0	2	1	0.920	0.690	0.690
0	1	1	1	1	1	0	1	3	1	0.914	0.690	0.762
1	0	1	1	0	0	1	0	2	1	0.938	0.677	0.692
1	0	0	0	1	1	0	0	4	1	0.877	0.673	0.679
1	0	1	0	0	0	1	0	5	1	0.905	0.663	0.679
1	1	0	0	0	1	0	0	4	1	0.886	0.662	0.662
1	1	0	1	0	1	0	0	3	1	0.873	0.652	0.657
0	0	0	0	1	1	0	0	3	1	0.874	0.652	0.652
1	1	1	1	1	0	0	0	2	1	0.902	0.651	0.651
0	1	1	1	1	0	0	0	3	1	0.904	0.635	0.635
0	1	1	0	0	1	0	1	3	1	0.842	0.633	0.700
0	0	1	1	1	0	1	0	4	1	0.903	0.626	0.635
1	0	1	0	1	1	0	0	2	1	0.889	0.620	0.620
0	1	0	1	1	1	1	0	2	1	0.893	0.614	0.614
0	0	0	0	1	0	0	0	2	1	0.872	0.611	0.611
1	0	0	0	0	1	0	0	2	1	0.876	0.604	0.604
0	1	1	1	1	0	1	1	3	1	0.870	0.603	0.664
1	0	0	0	0	0	1	0	6	1	0.833	0.597	0.603
0	1	1	1	0	0	0	0	3	1	0.888	0.583	0.583
1	1	0	0	1	0	1	0	2	1	0.892	0.572	0.572
0	1	0	0	1	1	0	0	3	1	0.845	0.568	0.568
0	1	0	1	0	0	1	0	4	1	0.856	0.565	0.602
0	1	0	1	0	1	0	1	2	1	0.866	0.564	0.564
1	0	0	0	1	0	1	0	4	1	0.846	0.541	0.541
0	1	1	1	1	1	0	0	2	1	0.878	0.540	0.540

0	1	1	1	0	1	0	0	3	1	0.872	0.533	0.538
1	0	0	0	1	1	1	0	4	1	0.827	0.532	0.532
1	0	0	0	1	0	1	1	2	1	0.819	0.526	0.581
0	0	1	0	1	1	0	0	3	1	0.820	0.495	0.530
1	1	0	0	1	1	0	0	2	1	0.806	0.491	0.491
1	1	0	0	1	1	1	0	2	1	0.856	0.489	0.489
1	1	1	1	0	0	1	1	2	1	0.870	0.489	0.503
0	1	0	0	1	0	0	0	3	1	0.845	0.479	0.479
1	0	0	0	0	1	1	0	4	1	0.811	0.452	0.452
1	1	0	1	0	1	1	0	2	1	0.825	0.448	0.448
0	0	0	0	1	0	1	0	5	0	0.782	0.440	0.486
0	1	0	0	1	0	1	0	2	0	0.821	0.417	0.417
0	0	1	0	1	0	1	0	3	0	0.810	0.404	0.419
1	0	1	0	1	1	1	0	2	0	0.827	0.374	0.374
1	0	1	0	1	0	1	0	3	0	0.838	0.369	0.379
0	0	0	0	0	0	1	0	3	0	0.734	0.330	0.330
0	0	0	0	1	1	1	0	2	0	0.775	0.304	0.304

Appendix 2. Policy implementation pathways with high pollution reduction performance

Type	H1	H2		H3			H4		
		H2a	H2b	H3a	H3b	H3c	H4a	H4b	H4c
RE	●		⊗	⊗	⊗	⊗		⊗	⊗
MA		⊗	•		•	•	•	•	•
SU	⊗		⊗	•	⊗	•	⊗	⊗	•
IN	⊗	⊗	⊗	●	●	●			⊗
IF		●	●		⊗		⊗		⊗
SE	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂
PR	⊗	⊗	⊗	⊗		⊗	⊗	⊗	
IV	•	•		•	•		•	•	•
Consistency	0.944	0.889	0.944	0.940	0.975	0.934	0.959	0.945	0.971
Raw Coverage	0.115	0.086	0.060	0.086	0.077	0.073	0.120	0.114	0.049
Unique Coverage	0.019	0.014	0.004	0.008	0.006	0.004	0.012	0.009	0.018
Type	H5		H6	H7		H8			
	H5a	H5b	H6a	H7a	H7b	H8a	H8b	H8c	
RE	●	●	●	⊗	⊗	●	●	●	
MA	•	⊗	•	⊗	•		⊗	⊗	
SU	•	⊗	•	•	•	•	⊗	•	
IN		⊗	●	●	●	⊗	⊗	⊗	
IF	●	●	⊗	●	●			⊗	
SE	•	•	•		•	•	•	•	
PR	⊗	⊗	•	•	•	⊗	⊗	•	
IV	⊗	⊗	⊗	•	⊗	⊗			
Consistency	0.977	0.858	0.959	0.903	0.895	0.916	0.881	0.936	
Raw Coverage	0.061	0.046	0.039	0.045	0.038	0.110	0.074	0.048	
Unique Coverage	0.003	0.006	0.007	0.003	0.005	0.026	0.018	0.015	
Solution Coverage	0.592								
Solution Consistency	0.902								

注：a.●=核心条件存在；⨂=核心条件缺失；•=边缘条件存在；⊗=边缘条件缺失；空白=条件冗余。b. RE=监管工具；MA=市场工具；SU=补贴工具；IN=创新支持工具（IN）；IF=信息提供工具；SE=环境问题严重性=；IV=企业创新积极性；PR=政府的环境目标。

Appendix 3. Policy implementation pathways with high carbon abatement performance

Type	S1				S2		S3			S4	S5	S6
	S1a	S1b	S1c	S1d	S2a	S2b	S3a	S3b	S3c			
RE	⊗	⊗	⊗	⊗	●	●	●	●	●	●	●	●
MA		⊗	•	•	⊗	⊗	⊗			●	●	●
SU	⊗	•	⊗	•	•	•	⨂	⨂	⨂	⨂	•	
IN	●	●	●	●		⊗	⊗	⊗	⊗		●	⊗
IF	⊗		•	•	⨂	⨂	•			⨂	⨂	
SE	•	•	•	•	•	•	•	•				•

IV	⊗	⊗	●	⊗	⊗	⊗	⊗		●	●	⊗	⊗
PR	⊗	⊗	⊗	●	⊗			⊗	⊗	⊗	●	⊗
Consistency	0.888	0.906	0.893	0.870	0.916	0.882	0.819	0.817	0.825	0.858	0.900	0.926
Raw Coverage	0.091	0.103	0.053	0.042	0.119	0.105	0.077	0.163	0.171	0.110	0.056	0.103
Unique Coverage	0.028	0.024	0.007	0.008	0.009	0.014	0.009	0.018	0.007	0.007	0.004	0.014
Type	***S7***				***S8***					***S9***	***S10***	
	S7a	***S7b***	***S7c***	***S7d***	***S8a***	***S8b***	***S8c***	***S8d***	***S8e***			
RE	⊗		⊗	⊗	⊗		⊗	⊗	⊗	⬤	⬤	
MA	●	⊗	●			●	●		●	⊗	⬤	
SU			●	⊗	●	●	●	●	⊗	●	●	
IN		⊗	⊗	⊗	⬤	⬤	⬤	⬤	⬤	⊗	⬤	
IF	⊗	●	⊗	●		●		●	⊗	⨂	⨂	
SE	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂	⨂	
IV	●	●	●		●	⊗		●	●	●		
PR	⊗	⊗		⊗	⊗	⊗	⊗			●	●	
Consistency	0.905	0.864	0.866	0.848	0.879	0.910	0.887	0.879	0.854	0.929	0.949	
Raw Coverage	0.125	0.114	0.063	0.110	0.122	0.078	0.107	0.118	0.093	0.047	0.066	
Unique Coverage	0.009	0.011	0.017	0.014	0.013	0.005	0.007	0.021	0.023	0.007	0.005	
Solution Coverage	0.720											
Solution Consistency	0.833											

Appendix 4. Policy implementation pathways with high pollution reduction performance

Type	***H1***					***H2***		***H3***	***H4***	***H5***			
	H1a	***H1b***	***H1c***	***H1d***	***H1e***	***H2a***	***H2b***						
RE			⊗	⊗	⬤	⊗	⊗	⬤	⊗	⊗		⬤	⬤
MA	⬤		⊗	⬤		⬤	⬤	⬤	⬤		⊗	⊗	⊗
SU	⊗	⊗			⊗	⬤	●	●	●	⊗	⬤	⊗	⬤
IN		⊗	⊗	⬤	⊗	⨂	●	⬤	●	⬤	⨂	⊗	⨂
IF	⊗	●	●	⨂		⊗	●	⨂	●	⨂	●	⊗	⊗
SE	⊗	⊗	⊗	⊗	⊗	⊗	⊗	●	●	●	●	●	●
IV	⬤	⬤	⬤	⬤	⬤	⬤	⬤	⊗	⊗	⊗	⊗		⊗
PR	⊗	⊗	⊗	⊗	⊗	●	●	●	●	⊗	⊗	⊗	
Consistency	0.120	0.108	0.051	0.077	0.114	0.039	0.048	0.039	0.038	0.070	0.090	0.056	0.078
Raw Coverage	0.020	0.012	0.006	0.003	0.010	0.016	0.013	0.009	0.006	0.032	0.041	0.018	0.027
Unique Coverage	0.959	0.906	0.880	0.941	0.944	0.967	0.954	0.959	0.895	0.900	0.912	0.898	0.926
Solution Coverage	0.426												
Solution Consistency	0.914												

Appendix 5. Policy implementation pathways with high pollution reduction performance

Type	***H1***	***H2***	***H3***	***H4***

	H1a	*H1b*	*H1c*	*H2a*	*H3a*	*H3b*	*H3c*	
RE	●	⊗	⊗	●	●		●	●
MA	⊗	•	⊗	•	•	•		⊗
SU		⊗	●	●	⊗	⊗	⊗	●
IN	⊗	•	⊗	•	⊗	•	⊗	⊗
IF	⊗	⊗	•	⊗		⊗	•	⊗
SE	⊗	⊗	⊗	⊗	•	•	•	⊗
IN	•	•	•	•	⊗	⊗	⊗	•
PR	⊗	⊗	⊗	•	⊗	⊗	⊗	
Consistency	0.079	0.048	0.063	0.039	0.071	0.090	0.081	0.078
Raw Coverage	0.014	0.012	0.033	0.013	0.015	0.045	0.027	0.014
Unique Coverage	0.904	0.893	0.932	0.959	0.956	0.974	0.931	0.926
Solution Coverage	0.297							
Solution Consistency	0.935							

Appendix 6. Policy implementation pathways with high carbon abatement performance

Type	***H1***				***H2***	***H3***		***H4***
	H1a	***H1b***	***H1c***	***H1d***	***H2a***	***H3a***	***H3b***	
RE	●	⊗	⊗	●	●	●	⊗	⊗
MA	⊗	⊗	•	⊗	⊗	•	•	•
SU	●	●	⊗		●	●	●	●
IN			●	⊗	⊗	●	●	●
IF	⊗	•	⊗		⊗	⊗	•	•
SE	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
IN	•	•	•	•	•	•	•	⊗
PR	⊗	⊗	⊗	⊗		•	•	⊗
Consistency	0.123	0.125	0.064	0.157	0.106	0.043	0.044	0.064
Raw Coverage	0.018	0.044	0.020	0.006	0.015	0.007	0.010	0.009
Unique Coverage	0.916	0.837	0.847	0.800	0.881	0.878	0.875	0.906
Type		***H8***		***H9***	***H10***		***H11***	
	H8a	***H8b***	***H8c***		***H10a***	***H10b***	***H11a***	***H11b***
RE	⊗	⊗	⊗	●	⊗		⊗	●
MA	•		⊗	•	•	⊗	⊗	⊗
SU	●	⊗		⊗		⊗	●	⊗
IN	⊗	⊗	⊗		●	⊗	●	⊗
IF	⊗	•	•	⊗	⊗	•	•	
SE	•	•	•	•	•	•	•	

IN	⊗	⊗	⊗	⊗	⊗	⊗	•	•
PR	•	⊗	⊗	⊗	⊗	⊗	•	⊗
Consistency	0.048	0.087	0.070	0.087	0.100	0.089	0.045	0.122
Raw Coverage	0.018	0.019	0.008	0.026	0.029	0.023	0.010	0.015
Unique Coverage	0.856	0.865	0.855	0.865	0.886	0.896	0.890	0.796
solution coverage	0.542							
solution consistency	0.818							

Appendix 7. Policy implementation pathways with high carbon abatement performance

Type	***H1***		***H2***		***H3***	***H4***
	H1c	***H1d***	***H2a***	***H2b***		
RE	●	⊗	⊗	⊗	●	●
MA	•	•	⊗	•	⊗	⊗
SU	⊗	⊗	●	⊗	⊗	●
IN	⊗	●		●	⊗	⊗
IF	⊗	⊗	•	⊗		⊗
SE	⊗	⊗	•	•	•	•
IN	⊗	⊗	⊗	⊗	⊗	
PR	•	•	⊗	⊗		⊗
Consistency	0.060	0.085	0.125	0.064	0.122	0.106
Raw Coverage	0.024	0.044	0.070	0.021	0.064	0.051
Unique Coverage	0.883	0.890	0.837	0.847	0.796	0.881
solution coverage	0.371					
solution consistency	0.828					

Appendix 8. Policy implementation pathways with high pollution reduction performance

Type	***H1***					***H2***		***H3***		***H4***	***H5***	***H6***
	H1a	***H1b***	***H1c***	***H1d***	***H2a***							
RE	•		⊗		⊗	•	⊗	⊗	⊗	●	⊗	●
MA		•	•	⊗		⊗		•	•	•	⊗	⊗
SU	⊗	⊗	⊗		•		•	•	⊗	•	•	•
IN	⊗			⊗	●	⊗	●	⊗	●	●	●	⊗
IF		⊗		●		●	•	⊗	⊗	⊗	•	⊗
SE	●	●	●	●	●	●	●	●	●	●	●	

IV	⊗	⊗	⊗	⊗	⊗		⊗	⊗	⊗	⊗		•
PR	⊗	⊗	⊗	⨂	⊗	⨂				•	•	•
Consistency	0.115	0.120	0.114	0.086	0.086	0.084	0.082	0.049	0.077	0.041	0.045	0.048
Raw Coverage	0.019	0.012	0.009	0.014	0.008	0.004	0.009	0.018	0.006	0.004	0.003	0.015
Unique Coverage	0.944	0.959	0.945	0.889	0.940	0.937	0.931	0.971	0.975	0.954	0.903	0.936
Type			***H7***				***H8***		***H9***		***H10***	***H11***
	H8a	***H8b***	***H8c***		***H10a***	***H10b***	***H11a***	***H11b***				
RE	⊗		⊗	•	•	●	⊗		⊗	⊗	•	•
MA			⊗	•		•	•	⊗	•	•	⊗	⊗
SU		⊗		•	•	•	•	•	•	⊗	⊗	⊗
IN	●	⊗			⊗	●	●	●	●	⊗	⊗	⊗
IF	⊗	●	●	●		⊗	•	⊗		●		●
SE	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗				
IV	•	•	•	•	•	•	•	•	⊗	⊗	•	
PR	⊗	⨂	⨂	⨂	⊗	•	•	•	⊗	⨂	⊗	⨂
Consistency	0.096	0.091	0.117	0.061	0.110	0.039	0.038	0.069	0.073	0.060	0.074	0.083
Raw Coverage	0.016	0.009	0.026	0.003	0.026	0.007	0.005	0.007	0.004	0.004	0.018	0.007
Unique Coverage	0.887	0.885	0.859	0.977	0.916	0.959	0.895	0.925	0.934	0.944	0.881	0.904
solution coverage						0.586						
solution consistency						0.903						

Appendix 9. Policy implementation pathways with high carbon abatement performance

Type			***H1***				***H2***		***H3***	***H4***	***H5***
	H1a	***H1b***	***H1c***	***H1d***	***H1e***	***H2a***	***H2b***	***H2c***			
RE			•	⊗	•	⊗	⊗	⊗	•	⊗	●
MA	•	⨂	⊗		⨂	●	•	•	●	•	•
SU	⊗	⨂		•	⨂	●	⊗	•	⊗	⊗	●
IN		⊗	⊗	●	⊗	⨂	●	●	⨂	●	●
IF	⊗	•	•	●		⨂	⊗	●	⨂	●	⨂
SE	•	•	•	•	•	•	•	•	•	•	•
IV	⊗	⨂	⊗	⨂	⨂	⊗	⨂	⨂		•	⨂
PR	⊗	⊗	⊗	⊗	⊗				⊗	⊗	•
Consistency	0.138	0.089	0.082	0.086	0.083	0.063	0.093	0.084	0.076	0.053	0.056
Raw Coverage	0.016	0.018	0.005	0.007	0.010	0.017	0.004	0.009	0.004	0.009	0.008
Unique Coverage	0.877	0.896	0.896	0.906	0.875	0.878	0.854	0.871	0.899	0.892	0.945
Type			***H6***			***H7***		***H8***	***H9***	***H10***	

	H6a	*H6b*	*H6c*	*H6d*	*H6e*	*H7a*	*H7b*			
RE	⊗	●		•	⊗	●	⊗	•	⊗	⊗
MA	⨂	●	●	⊗		●	•	⊗	•	⨂
SU			⊗	●	●	●	•	●	●	•
IN	●	⊗	⨂		•	●	●	⊗	●	●
IF			⨂	⨂	⨂	⨂	●	⨂		●
SE	⊗	⨂	⊗	⊗	⊗	⨂	⊗			•
IV	•	•	•	•	•	•	•	•	⊗	•
PR	⊗	⊗	⊗	⊗	⊗	•	•	•	⊗	•
Consistency	0.139	0.105	0.072	0.123	0.094	0.043	0.044	0.063	0.103	0.045
Raw Coverage	0.045	0.024	0.006	0.043	0.005	0.006	0.010	0.018	0.017	0.004
Unique Coverage	0.883	0.921	0.901	0.916	0.934	0.878	0.875	0.869	0.886	0.890
Solution coverage						0.592				
solution consistency						0.867				

Appendix 10. Regression Analysis of the Influence of Main Effects and Configurations on Pollution Control

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	H1	***H2a***	***H2b***	***H3a***	***H3b***	***H3c***	***H4a***	***H4b***	***H4c***	***H5a***	***H5b***	***H6a***	***H7a***	***H7b***	***H8a***	***H8b***	***H8c***
Main effects																	
RE（core）	0.109*	0.115**	0.100*	0.107*	0.114**	0.109**	0.104*	0.111*	0.127**	0.097*	0.111*	0.107*	0.112**	0.106*	0.081	0.113**	0.107**
	(1.79)	(2.19)	(2.02)	(2.04)	(2.18)	(2.10)	(2.03)	(2.03)	(2.40)	(1.83)	(2.00)	(2.05)	(2.24)	(2.04)	(1.46)	(2.29)	(2.11)
MA	0.058*	0.035	0.074*	0.060*	0.044	0.062*	0.037	0.056	0.042	0.040	0.057*	0.054	0.062*	0.062*	0.050	0.056*	0.060
	(1.76)	(0.88)	(1.91)	(1.82)	(1.26)	(1.78)	(0.89)	(1.40)	(1.09)	(1.04)	(1.72)	(1.57)	(1.93)	(1.78)	(1.31)	(1.90)	(1.68)
SU	0.237*	0.240*	0.222*	0.251**	0.228*	0.242**	0.239**	0.237*	0.222*	0.225*	0.237*	0.234*	0.237**	0.237**	0.196	0.236*	0.234*
	(2.01)	(2.00)	(2.00)	(2.29)	(2.00)	(2.17)	(2.06)	(2.02)	(1.93)	(1.93)	(2.03)	(2.03)	(2.08)	(2.06)	(1.34)	(2.04)	(2.02)
IN（core）	0.039*	0.029*	0.027*	0.048*	0.014*	0.041*	0.029*	0.038*	0.052*	0.034*	0.038*	0.035*	0.026*	0.045*	0.058*	0.038*	0.040
	(0.71)	(0.63)	(0.57)	(0.85)	(0.26)	(0.81)	(0.55)	(0.78)	(1.05)	(0.72)	(0.81)	(0.69)	(0.46)	(0.89)	(1.30)	(0.81)	(0.82)
IF（core）	0.011	0.032	0.023	0.012	0.022	0.012	0.029	0.011	0.030	0.001	0.012	0.011	-0.000	0.017	0.012	0.010	0.014
	(0.25)	(0.76)	(0.49)	(0.26)	(0.47)	(0.25)	(0.62)	(0.25)	(0.63)	(0.02)	(0.25)	(0.24)	(-0.00)	(0.36)	(0.27)	(0.23)	(0.31)
SE（core:se）	-0.498***	-0.511***	-0.503***	-0.517***	-0.515***	-0.503***	-0.509***	-0.500***	-0.486***	-0.510***	-0.496***	-0.502***	-0.499***	-0.491***	-0.533***	-0.495***	-0.499***
	(-3.44)	(-3.49)	(-3.60)	(-3.63)	(-3.60)	(-3.57)	(-3.50)	(-3.46)	(-3.33)	(-3.54)	(-3.22)	(-3.43)	(-3.51)	(-3.34)	(-3.41)	(-3.54)	(-3.46)
IV	0.265	0.242	0.277	0.258	0.296	0.267	0.297	0.265	0.268	0.257	0.262	0.264	0.278	0.272	0.271	0.262	0.262
	(0.20)	(0.23)	(0.50)	(0.29)	(0.65)	(0.31)	(0.41)	(0.37)	(0.26)	(0.24)	(0.08)	(0.31)	(0.27)	(0.43)	(0.32)	(0.26)	(0.31)
PR	-0.151*	-0.163**	-0.152*	-0.166**	-0.147*	-0.157**	-0.138*	-0.151*	-0.173**	-0.148*	-0.152*	-0.159*	-0.169**	-0.141*	-0.130	-0.153*	-0.157**
	(-1.86)	(-2.08)	(-2.02)	(-2.23)	(-1.88)	(-2.12)	(-1.71)	(-1.88)	(-2.40)	(-1.92)	(-1.98)	(-1.96)	(-2.17)	(-1.71)	(-1.52)	(-1.97)	(-2.12)
Configuration																	
H_i Pathway	0.005*	0.187	0.173	0.080	0.226*	0.041	0.147*	0.013*	0.297*	0.176*	0.024	0.079*	0.197*	0.125	0.175*	0.024	0.053*
	(0.03)	(1.14)	(1.41)	(0.42)	(1.78)	(0.21)	(0.95)	(0.09)	(1.64)	(1.58)	(0.06)	(0.75)	(0.51)	(0.56)	(0.69)	(0.14)	(0.38)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.244***	1.257***	1.271***	1.254***	1.282***	1.246***	1.263***	1.244***	1.224***	1.257***	1.241***	1.251***	1.250***	1.239***	1.273***	1.243***	1.241***
	(7.71)	(7.93)	(8.31)	(7.76)	(8.19)	(7.77)	(7.78)	(7.75)	(7.40)	(7.89)	(6.94)	(7.58)	(7.79)	(7.61)	(7.31)	(7.76)	(7.66)
N	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254
R^2	0.219	0.225	0.222	0.220	0.226	0.219	0.223	0.219	0.227	0.221	0.219	0.219	0.222	0.220	0.223	0.219	0.219

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Appendix 11. Regression Analysis of the Influence of Main Effects and Configurations on Carbon Abatement

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
	S1a	***S1b***	***S1c***	***S1d***	***S2a***	***S2b***	***S3a***	***S3b***	***S3c***	***S4***	***S5***	***S6***	***S7a***	***S7b***	***S7c***	***S7d***	***S8a***	***S8b***	***S8c***	***S8d***	***S8e***	***S9***	***S10***
Main effects																							
RE	0.045	0.039	0.044	0.032	0.053	0.045	0.027	0.015	0.031	0.043	0.047	0.017	0.039	0.033	0.048	0.030	0.036	0.039	0.034	0.040	0.036	0.039	0.050
	(0.75)	(0.64)	(0.71)	(0.53)	(0.79)	(0.71)	(0.42)	(0.23)	(0.43)	(0.70)	(0.76)	(0.24)	(0.64)	(0.54)	(0.82)	(0.50)	(0.60)	(0.64)	(0.55)	(0.65)	(0.59)	(0.63)	(0.80)
MA	0.080*	0.073*	0.093**	0.075*	0.091*	0.084*	0.068*	0.074*	0.071*	0.064*	0.066*	0.104**	0.083*	0.062*	0.090**	0.077*	0.078*	0.070*	0.066	0.084*	0.077*	0.078*	0.067*
	(2.60)	(2.18)	(2.97)	(2.45)	(2.44)	(2.30)	(1.95)	(2.11)	(2.02)	(1.83)	(2.03)	(3.04)	(2.24)	(2.03)	(2.79)	(2.47)	(2.43)	(2.00)	(1.68)	(2.50)	(2.37)	(2.38)	(1.98)
SU	0.097	0.073	0.069	0.078	0.104	0.090	0.092	0.107	0.097	0.100	0.090	0.080	0.072	0.080	0.068	0.073	0.077	0.084	0.094	0.063	0.078	0.077	0.085
	(0.80)	(0.60)	(0.56)	(0.64)	(0.85)	(0.72)	(0.77)	(0.92)	(0.83)	(0.83)	(0.73)	(0.63)	(0.61)	(0.65)	(0.54)	(0.59)	(0.61)	(0.68)	(0.74)	(0.50)	(0.64)	(0.63)	(0.68)
IN(core)	0.014	0.001	0.012	0.016	0.013	0.003	0.012	0.020	0.012	0.019	0.025	0.022	0.008	0.019	0.019	0.005	0.010	0.015	0.019	0.005	0.012	0.010	0.025
	(0.25)	(0.02)	(0.27)	(0.36)	(0.30)	(0.07)	(0.27)	(0.47)	(0.27)	(0.45)	(0.57)	(0.51)	(0.18)	(0.46)	(0.46)	(0.12)	(0.20)	(0.34)	(0.41)	(0.10)	(0.28)	(0.23)	(0.54)
IF	0.014	0.002	0.015	0.005	0.022	0.012	0.011	0.003	0.003	0.005	0.002	0.005	0.005	0.014	0.012	0.005	0.001	0.007	0.002	0.018	0.002	0.002	0.004
	(0.24)	(0.03)	(0.30)	(0.09)	(0.36)	(0.20)	(0.19)	(0.06)	(0.05)	(0.09)	(0.03)	(0.10)	(0.08)	(0.26)	(0.23)	(0.10)	(0.01)	(0.12)	(0.04)	(0.32)	(0.03)	(0.04)	(0.08)
SE(core:se)	-0.347**	-0.346**	-0.357**	-0.328**	-0.311**	-0.332**	-0.324**	-0.339**	-0.319**	-0.321**	-0.346**	-0.352**	-0.333**	-0.323**	-0.340**	-0.348**	-0.337**	-0.339**	-0.346**	-0.335**	-0.336**	-0.340**	-0.364**
	(-2.67)	(-2.62)	(-2.72)	(-2.46)	(-2.19)	(-2.44)	(-2.48)	(-2.56)	(-2.51)	(-2.42)	(-2.44)	(-2.60)	(-2.50)	(-2.21)	(-2.56)	(-2.37)	(-2.33)	(-2.55)	(-2.54)	(-2.51)	(-2.52)	(-2.48)	(-2.51)
IV	-0.092	-0.092	-0.107	-0.104	-0.111	-0.106	-0.136	-0.140	-0.137	-0.118	-0.098	-0.084	-0.101	-0.109	-0.100	-0.102	-0.098	-0.107	-0.105	-0.116	-0.096	-0.100	-0.103
	(-0.91)	(-0.90)	(-1.01)	(-1.03)	(-1.10)	(-1.03)	(-1.32)	(-1.33)	(-1.30)	(-1.10)	(-0.99)	(-0.83)	(-1.01)	(-1.07)	(-1.01)	(-1.01)	(-0.95)	(-1.08)	(-1.04)	(-1.17)	(-0.95)	(-0.98)	(-1.02)
PR	0.072	0.071	0.072	0.080*	0.047	0.064	0.053	0.067	0.063	0.060	0.091*	0.077	0.077*	0.081	0.053	0.069	0.069	0.063	0.050	0.068	0.068	0.070	0.091*
	(1.47)	(1.53)	(1.49)	(1.80)	(0.96)	(1.36)	(1.26)	(1.38)	(1.35)	(1.42)	(2.02)	(1.60)	(1.77)	(1.65)	(1.13)	(1.53)	(1.22)	(1.38)	(0.99)	(1.48)	(1.53)	(1.48)	(2.05)
Other core																							
*RE*su*							0.106*	0.113*	0.109*	0.132*													
							(-1.75)	(-1.83)	(-1.79)	(-1.82)													
*RE*if*					0.011	0.017				0.017	0.028							-0.123				-0.016	-0.028
					(-0.19)	(-0.28)				(0.24)	(-0.47)							(-0.93)				(-0.26)	(-0.46)
*RE*MA*										0.052	0.041	0.024											0.035
										(0.84)	(0.69)	(0.42)											(0.59)
Configuration																							
H_i Pathway	0.186	0.072	0.449**	0.138	0.207	0.102	0.101	0.104	0.027	0.065	0.211	0.160	0.056	0.141	0.217	0.057	0.003	0.123	0.116	0.134	0.022	0.037	0.203
	(1.21)	(0.40)	(2.59)	(0.70)	(1.14)	(0.85)	(0.81)	(0.90)	(0.18)	(0.34)	(1.27)	(1.09)	(0.36)	(0.98)	(1.04)	(0.38)	(0.02)	(0.93)	(0.98)	(1.33)	(0.18)	(0.34)	(1.49)
Year fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.838***	0.857***	0.892***	0.854***	0.880***	0.876***	0.899***	0.890***	0.888***	0.869***	0.843***	0.851***	0.854***	0.837***	0.852***	0.877***	0.859***	0.858***	0.862***	0.877***	0.857***	0.867***	0.860***
	(6.33)	(6.10)	(6.29)	(6.26)	(6.20)	(6.23)	(6.40)	(6.33)	(6.38)	(6.19)	(5.97)	(5.98)	(5.99)	(5.57)	(6.17)	(5.73)	(6.15)	(6.24)	(6.33)	(6.38)	(6.35)	(6.13)	(6.00)

N	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254	254
R^2	0.236	0.231	0.242	0.232	0.237	0.233	0.247	0.248	0.245	0.250	0.236	0.235	0.231	0.234	0.236	0.231	0.230	0.232	0.233	0.234	0.230	0.231	0.236

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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