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Policy Diffusion in Leadership Transfer Networks

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Abstract

Although some emerging research has recognized the significance of the network perspective in policy diffusion, our understanding of how the policy network structure affects policy diffusion's process and performance is limited. This article uses the method of social network analysis, focusing on network structure indicators, to investigate the impact of centrality and structural holes in the municipal leadership transfer networks on policy diffusion's performance. Furthermore, from the cross-layer network perspective, we assume that provincial leadership transfer networks' centrality and structural holes moderate the above relationship. Employing the panel data from an environmental field of 292 cities in China from 2003 to 2018, we find the relationship in the form of an inverted U-shape between centrality, structural holes in the municipal leadership transfer networks and the diffusion performance of environmental policies. High levels of centrality and structural holes in the provincial leadership transfer networks steepen the double inverted U-shaped relationship.

Keywords

policy diffusion; leadership transfer; social network analysis; cross-layer network; environmental performance

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1. Introduction

Policy diffusion is usually defined as a government's choice to adopt a policy that is influenced by the choices of other governments (Rogers *et al*., 2014). Research literature on this topic has explored multiple diffusional mechanisms, including competition, learning, and coercion (Berry and Berry, 1990; Gray, 1973; Shipan and Volden, 2008; Walker and Jack, 1969; Berry and Berry, 1992). These mechanisms indicate that policy diffusion is a complex and interactive process. Braun and Gilardi (2006) regarded that governments made choices interdependently in the process of policy diffusion. These governmental interactions will eventually form an intricate network. Berry and Berry (1990) previously developed a neighboring state diffusion model and found that it did boost policy diffusion. An increasing amount of research indicates that policy diffusion occurs not only among geographically adjacent regions, but also among governments with similar economic, social, and cultural characteristics (Liu and Yi, 2021; Yi *et al*., 2018; Yi and Chen, 2019; Zhu and Zhang, 2019). Specifically, geographical boundaries are even more insignificant to policy diffusion, which scholars should have a holistic network perspective on. However, the extant research largely ignores the importance of policy network structure in policy diffusion. There is an important theoretical and empirical question — how does the policy network structure affect policy diffusion from the overall network perspective?

The policy network perspective is important in explaining the process of policy diffusion. The network perspective emphasizes multiple connections among individuals, political actors, and different organizations (Marin and Wellman, 2011). Compared with a traditional perspective to understanding policy diffusion, which focuses on the horizontal and vertical levels of diffusion mechanisms (Zhu and Zhang, 2019), social network analysis to explore the same process would pay attention to intergovernmental contacts and interactions, such as how mobility between policy actors and government agencies has created connections (Marin and Wellman, 2011). Some recent developments have raised the idea that policy networks might influence policy diffusion (Lubell *et al*., 2012). The interaction process of governments has been emphasized by some earlier policy diffusion literature (Simmons and Elkins, 2004; Braun and Gilardi, 2006), which focused on the characteristics and consequences of intergovernmental interaction. Some scholars have developed a network perspective to better explain policy issues (Dorussen and Ward, 2010). For example, Chyzh (2016) explored human rights diffusion by trade networks; Haim (2016) examined the impact of international political alliance networks on trade flows. Mohrenberg (2017) investigated how foreign trade policies diffused via bilateral trade flows. Until Yi *et al*. (2018) first constructed the agent network diffusion (AND) model[1], some research on the network perspective appeared in policy diffusion. They found that the leadership transfer network channel facilitates policy diffusion among cities where officials served/serve coincidentally.

Regrettably, although emerging research has emphasized policy networks in policy diffusion, most of them have solely focused on the impact of the network composition and tie properties on policy diffusion (Kammerer and Namhata, 2018). The structural properties of policy networks are widely ignored in the policy diffusion process. The network structure provides a holistic perspective to explore policy diffusion processes, which entail the analysis of interdependent interactions rather than independent components as complex systems. Therefore, the impact of network structure on policy diffusion is necessary to be elucidated.

[1] The agent network diffusion (AND) model was proposed to test how leadership transfer networks facilitated the diffusion of energy performance across jurisdictions with spatial regressions. It offers a perspective of network-based explanation for policy diffusion.

To fill the gap, we explore how the policy network structure affects policy diffusion's performance from a social network analysis perspective. We firstly pay attention to leadership transfer networks, in which officials' turnover from one city to another brings their ideas, expertise, and tacit knowledge (Li and Zhou, 2005). Additionally, these officials also bring their connections with former coworkers, many of whom have transferred to new cities. This pattern of connections among governments via their policy actors enables each government to draw on various knowledge sources. According to the AND model (Yi *et al*., 2018), we construct the leadership transfer network to answer the above research question.

We focus on the centrality and structural holes of leadership transfer networks. Centrality refers to an actor's capability to control communication and information flow within the network, indicating the node's status. Structural holes represent nonredundant connections and measure actors' scarce resources and competitive advantages (Carrington *et al*., 2005, Das *et al*., 2018, Fritsch and Kauffeld, 2010). These indicators combining the location and structure of the network, affect the performance of environmental policy diffusion. Higher network structure indicators bring actors in these nodes more network resources and competitive advantages, which will benefit the diffusion performance of environmental policies. However, policy actors' behaviors are also affected by the promotion system for Chinese officials (Li and Zhou, 2005; Chen *et al*., 2005). Du and Yi (2021) demonstrated that the political promotion goals could affect the actors' motivation to implement environmental policies, although policy actors are influential in the network. Therefore, considering these two opposite influence mechanisms, we hypothesize that betweenness centrality and structural holes in the municipal leadership transfer network have an inverted U-shaped relationship with the performance of environmental policy diffusion.

Furthermore, based on the cross-layer network perspective, higher-level contextual factors moderate the relationships in lower-level analysis, thereby playing a cross-level regulatory role. We assume that centrality and structural holes in provincial leadership transfer networks moderate the double inverted U-shaped relationship in such a way that the curves will be steeper in nodes with high centrality or structural holes in the provincial leadership transfer network. In the process of decentralization and implementation of the policy, we have to consider the influence of multilevel governments. However, previous studies on policy diffusion do not pay attention to the interaction between cross-layer networks. This cross-layer perspective emphasizes cross-level effects and processes, which can more profoundly reveal the relationship between different levels of organizations and have more profound theoretical insights into the entire system (Rousseau, 1985). Therefore, we further want to explore how the top-down contextual impact moderates the double inverted U-shaped relationship with the performance of environmental policy diffusion. We construct provincial leadership transfer networks as the moderating networks, whose centrality and structural holes are measured as corresponding moderating variables. We assume that high levels of centrality and structural holes in the provincial leadership transfer networks steepen the double inverted U-shaped relationship.

We examine our hypothesis using a panel data from the Chinese environmental field in 292 cities over a 16-year period from 2003 to 2018. In China, many environmental policies have been implemented with the responsibility system of environmental pollution governance (Zhang and Wen, 2008). Approximately 60 years of environmental policy implementation also better guarantees enough time for us to research the policy diffusion process.

By network-based explanation for policy diffusion, we broaden the research methods to policy diffusion. We specifically test the influence of municipal leadership transfer network structure on environmental governance performance. A second contribution comes from the application of a novel

perspective, namely the cross-level moderating effects. This application allows us to analyze the impact of the provincial level on the municipal level in the process of policy diffusion. Our research also has a societal significance, in that officials will be better predicted and intervened in the process of policy diffusion.

In the following section, we overview the literature on social network analysis for policy diffusion, concentrating on this new perspective's enlightenment on analyzing policy diffusion. We then review the cross-layer theory and advance new hypotheses, detailing the top-down contextual impact. Then, we offer our data, variable measurement, and statistical model. Next, we report the findings. Finally, the study comes to a conclusion with a discussion of the theoretical contributions, limits, and prospects.

2. Theory and Hypotheses

2.1. A network perspective: Social network analysis for policy diffusion

Social network theory expounds that each participant and behavior should be regarded as interdependent rather than independent in a certain social relationship (Scott, 1988). Participants are linked precisely by exchanging their material and nonmaterial resources to each other (Dobbin *et al*., 2007; Mintrom and Vergari, 1998; True and Mintrom, 2001). The network structure will provide opportunities or restrictions for individual actions, and structure (social, economic, political, *etc*.) is the long-term relationship model between participants (Wasserman and Faust, 1994). Political researchers have noticed the "relational turn" in politics. They have started using and refining network techniques to evaluate political issues (McClurg and Young, 2011) and connect network structure, macrolevel choices, and micro-level behavior (Fowler *et al*., 2011). Social network analysis methods in research in public governance are gradually merging (Siegel, 2009). The application of social network analysis methods to study political participation, public crisis governance, public resource governance, *etc*., has become an important research direction (Cullen and Sommer, 2010; Naim *et al*., 2010). The rise of regional public management increasingly coincides with the network trend of intergovernmental relations.

Although the literature on social network analysis for policy management is increasing, little research has explored the effects of policy network structure on diffusion. Some paid attention to public managers in network governance, exploring how managerial strategies impact perceived network outcomes (Klijn *et al*., 2010; Verweij *et al*., 2013). The emerging research has provided chances to use social network analysis to explore policy diffusion (Lubell *et al*., 2012). Yi *et al*. (2018) demonstrated that the leadership transfer network could channel policy diffusion among cities. Yi and Chen (2019) found that policy diffusion was portable, and cities would learn from each other via the career transferred paths of public managers. Our study will build on the preceding literature to further explore the influence of leadership transfer network structure on the performance of environmental policy diffusion.

Absolutely, it is effective to apply social network analysis to study policy diffusion. As we construct leadership transfer networks, they are important channels to communicate and disseminate policy ideas. In our study, we selected as samples two types of officials (party chiefs and mayors) who ranked high in leadership and power. The statistical results show that 754 party chiefs and 787 mayors are transferred among 292 cities from 2003 to 2018. In addition, these officials' transfers among cities lead to a total of 741 transfer paths. Figure 1 presents a visualization of the municipal leadership transfer network in 2018. In this network, the nodes are the cities, and the links represent the career paths of municipal officials who transferred from one city to another. The career paths are directional, with arrowed linkages

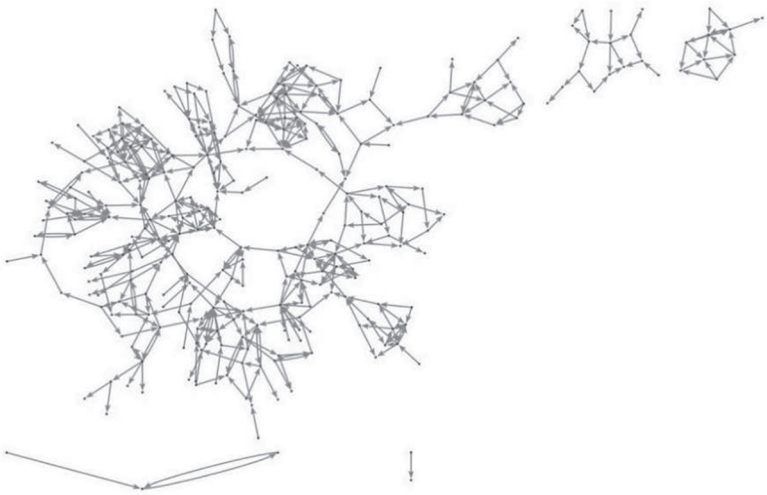

Fig. 1. The municipal leadership transfer network in 2018.

indicating the direction of the career transfers of party chiefs and mayors. As most cities are involved in the leadership transfer network, it is shown that we can effectively conduct research on policy diffusion from the perspective of network structure. We expect that using social network analysis will better assist us to explore the relationship between the leadership transfer network structure and the performance of environmental policy diffusion.

2.2. The trade-off between environmental governance and economic development

As green growth and sustainable development become increasingly important in political conversations, environmental governance is generally considered a promising policy to control pollution and realize green development. The Chinese economy has grown rapidly in recent decades, followed by resource consumption and environmental pollution. Domestic environmental challenges are mostly generally based on the pattern of economic development associated with the mechanisms of government incentives (Cai *et al*., 2008). The conflicts between the economy and the environment, also make environmental policy diffusion difficult (Howes *et al*., 2017). Thus, it is vital to investigate how the performance of environmental policy diffusion is affected by environmental governance.

Various studies have examined the conflicts between the dynamics of economic development and the goals of environmental policy. Li and Zhou (2005) proposed the promotion tournament theory, which is a promotion mechanism designed by the superior government for the chief executive of multiple subordinate governments. Li and Liu (2019) developed a Tullock contest model[2] to explore the best target setting in a multilayered tournament-based organization. While pursuing short-term economic development, officials tend to prioritize economic growth (Yu, 2016). During the past decades, as the performance assessment system for officials emphasized economic rather than environmental factors, and

[2] The Tullock contest model refers to an incentive mechanism that determines the winner or loser based on relative rankings rather than absolute results. In the political field, the model shows a positive relationship between the promotion of local officials and local economic performance.

they were more likely to be promoted because of their contributions to economic development (Li and Zhou, 2005). In terms of leadership transfer, asymmetric motivations make officials likely to prefer the goal of economic growth over environmental protection (Hong *et al*., 2019). However, as officials' tenure increases, multitasking makes their primary performance targets change, and increasing information and resources accumulated by them can eliminate asymmetric motivations. It is particularly important to study this process from a long-term perspective. Therefore, we will investigate how the cross-regional transfer of government officials affects the diffusion of environmental policy in temporal and spatial dimensions, based on the existing incentive model for officials in China.

In addition to the effect of promotion tournaments on environmental policy diffusion, previous theories from the network perspective indicate that leadership transfer networks can promote policy diffusion. The leadership transfer network structure is highly relevant to policy performance, since a policy actor's social capital is deeply integrated into the network structure, and no one network actor can efficiently handle the policy outcomes in a complex governance system (Burt *et al*., 2013). Yi *et al*. (2018) developed the AND model to explain the leadership transfer network could channel policy diffusion among cities. Expanding the AND model, Yi and Chen (2019) further explored that policy diffusion is portable and that cities may learn from others with whom officials have worked. Therefore, we can conclude that officials' transfer can promote policy diffusion.

Based on the above negative and positive latent mechanisms, we theorize an inverted U-shaped relationship between two important network structure indicators and the diffusion performance of environmental policy.

In terms of the centrality in the municipal transfer network, cities with higher centrality are in a necessary and important connectivity position in the network, mastering more different kinds of resources. Additionally, other cities will also depend on these cities as bridges to communicate with each other. When one city in the leadership transfer networks is in a low centrality, the local officials will control fewer resources and lower policy status. If they want to meet their own promotion needs within a short time, they need to send more explicit signals to their superiors than leaders with high network centrality. The dominant signal usually refers to economic growth (Li and Zhou, 2005). Considering Chinese officials' promotion incentives, officials with low network centrality have a strong driving force to maximize economic benefit at the beginning of the term of office. As the officials' centrality in the leadership transfer network gradually increases, they have more resources and higher policy experiences. Additionally, they will be confronted with increasing multitasking performance targets, and prioritize environmental protection over economic growth in the context of current national governance. Overall, the positive and negative latent mechanisms lead to an inverted U-shaped relationship between centrality in the municipal leadership transfer network and the performance of environmental policy diffusion.

H1. Centrality in the municipal leadership transfer network has an inverted U-shaped relationship with the performance of environmental policy diffusion.

Structural holes can assist officials to obtain information advantage and control power. To some extent, structural holes in the municipal leadership transfer network could measure officials' acceptance of new environmental policies in their cross-regional transfer. Higher structural holes could associate the officials transferred in the jurisdiction with asymmetrical information and rare resources, which lead to their higher willingness to accept the diffusion of environmental policies (Zhu *et al*., 2017). Officials on the cross-regional transfer often receive asymmetrical incentives of transferred jurisdiction and have no effective routes to show their performance to their superiors for promotion when they are at a relatively

low level of structural holes. They are also more inclined to use the obvious indicators of economic growth to send signals to their superiors. Once they occupy enough powerful structural holes, they will value the integrated public performance of multitasking instead of regarding GDP growth as their primary political goal. At the same time, they will be more willing to accept new environmental policies. When the positive and negative latent processes are combined, they provide an inverted U-shaped relationship between structural holes in the municipal leadership transfer network and the performance of environmental policy diffusion.

H2. Structural holes in the municipal leadership transfer network have an inverted U-shaped relationship with the performance of environmental policy diffusion.

2.3. Cross-layer moderating and top-down policy diffusion

In China, environmental policies are generally released by the higher governments, and implemented by local governments. Among them, administrative orders from provincial governments are a powerful tool to promote the adoption of new policies by municipal governments (Zhu and Zhang, 2016). Specifically, provincial administrative orders provide municipal governments with policy solutions to social problems and assist them in reducing political risk. Besides, provincial governments have political power constraints on municipal governments (Li *et al*., 2019). The provincial (municipal) party chiefs can intervene environmental investment via administrative approval and resource allocation (Liu *et al*., 2021). Thus, higher-level governments have the power to control and restrict local officials, which will naturally form a cross-layer impact from the perspective of the network.

Some literature on top-down policy diffusion has found that top-down policy signals affect the mechanisms of policy diffusion, which moderate the effects of horizontal pressures on policy diffusion (Zhou *et al*., 2019). Top-down impact can deepen the understanding of lower-level innovation diffusion by revealing the nature of this specific contextual impact and ensuring that the sources of influence on diffusion performance can be traced to the correct influencing factors (Klein *et al*., 1994; Kozlowski and Klein, 2000; Rousseau, 1985). Generally, higher-level situational factors moderate the relationships in the lower-level analysis, thus playing a cross-layer moderating role (Rousseau, 1985; Klein *et al*., 1994). Moreover, according to previous research on the vertical mechanism of policy diffusion, higher-level governments often promote the policy diffusion of lower-level governments (Zhang and Zhu, 2019; Zhu and Zhang, 2019). Based on this moderating effect, our study explores how the provincial leadership transfer networks moderate the impact of municipal leadership transfer network structure on the performance of environmental policy diffusion.

To examine the above assumption, we follow the guidelines from Haans *et al*. (2016) to comprehensively explain the moderating effects. In terms of the positive latent mechanism, a higher level of municipal centrality brings more diverse resources and thereby increases the performance of environmental policy diffusion. In general, higher provincial centrality provides provincial officials with more resources and information advantages. When provincial governments give policy instructions to municipal governments, it is accompanied by the sharing of provincial information signals and resources. Thereby, the channels for municipal governments to obtain information and resources are enhanced so that municipal governments can better implement policies. As for the negative latent mechanism, a lower level of municipal centrality makes officials pay attention to achieving economic growth to prove themselves and thereby ignore environmental policy diffusion. We suggest that in low level of municipal centrality, officials would have not enough motivation to implement environmental policies.

At this stage, provincial officials put more energy into economic growth to seek career promotion, while municipal officials will also benchmark the behavior of provincial governments and pay less attention to environmental policies. Overall, centrality in the provincial leadership transfer network steepens the inverted U-shaped relationship between municipal centrality and the performance of environmental policy diffusion.

H3. Centrality in the provincial leadership transfer network will steepen the inverted U-shaped relationship between municipal centrality and the performance of environmental policy diffusion.

Similarly, provincial structural holes can also affect municipal governments' behaviors via networks. In terms of positive effects, we suggest that provincial structural holes can promote the benefit of municipal structural holes. Because the high provincial structural holes have more scarce resources and competitiveness, provincial governments have a higher acceptance degree of environmental policy diffusion. At the same time, it will send explicit signals to local governments to implement environmental policies and urge them to achieve environmental governance. In terms of negative effects, although the provincial structural holes of officials are increasing at the beginning of the transfer, their political competitiveness and resources are not enough to reduce their motivation to achieve promotion. Therefore, the provincial government's focus on economic growth will also make municipal governments converge. Overall, structural holes in the provincial leadership transfer network will steepen the inverted U-shaped relationship between municipal structural holes and the performance of environmental policy diffusion.

H4. Structural holes in the provincial leadership transfer network will steepen the inverted U-shaped relationship between municipal structural holes and the performance of environmental policy diffusion.

Figure 2 shows the framework of this study.

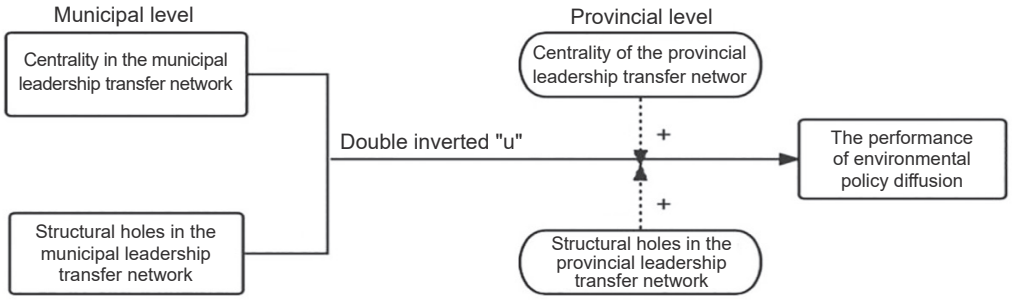

Fig. 2. Framework.

3. Methods and Results

3.1. Data

Three data sources are used to create our sample. First, we used the China City Statistical Yearbook to obtain discharge data of environmental pollutants. It documents all environmental acquisitions involving emissions of some environmental pollutants since 2003. We observed 292 cities in China and collected data for four kinds of environmental pollution emissions (industrial wastewater discharged, industrial sulfur dioxide and nitrogen dioxide emissions, industrial soot (dust) discharged, and the ratio of industrial solid wastes comprehensively utilized (total city)) between 2003 and 2018. To make full use of these data as controls, we refined the sample to include only cities that were established by the

municipal governments during this period. To keep the data consistent, we neglected certain cities that were severely lacking in various indicators from 2003 to 2018, such as Lhasa in 2006. In doing so, we built a sample of 4164 units (city-year).

Second, we tracked detailed information on the successive leaders of all provinces and cities since the founding of New China to build leadership transfer networks, which was also verified through municipal government websites. By integrating the name of party chiefs and mayors, their jurisdictions, and their corresponding jurisdictional time, we resorted to Excel functions to create the transfer paths of the leaders from 2003 to 2018. In particular, leadership transfer networks were presented per year and accumulated year by year.

Finally, we used the Local Leaders Database on the People's Daily Online (people.cn) to acquire leaders' personal information and employment experience. Then, we got 1292 resumes of Party secretaries and 1460 mayors' resumes. By making use of these leaders' resumes, we integrated some characteristics of leaders as control variables, such as leaders' age, gender, educational qualifications, and employment experience.

3.2. Dependent variable

The Environmental Pollution Index (EPI) is used as a dependent variable to capture the performance of environmental policy diffusion, measured by the entropy method. We use an integrated index of environmental pollution that considers multiple environmental pollution indicators, including industrial wastewater discharge, industrial sulfur dioxide and nitrogen dioxide emissions, industrial soot (dust) discharge, and the ratio of industrial solid wastes comprehensively utilized. The higher the Environmental Pollution Index is, the worse the environmental quality, which means the worse the performance of environmental policy diffusion in our study.

3.3. Independent variables

To test our hypotheses, we first establish leadership transfer networks. Based on the leader transfer data, we code the transfer events of officials in China over 16 years. If an official worked in city *j* before 2008 and transferred to city *i* in 2008 and stayed on until 2012, we define a link from city *j* to city *i* between 2008 and 2012 and code "1" for the years 2008 to 2012. If *j* and *i* are independent between 2006 and 2007, the dyad is coded as "0" for 2006 and 2007. Ultimately, we find 741 transfer paths out of the 15495 pieces of information gathered.

On this basis, we continue to construct two independent variables by using two types of social network structure indicators. Centrality and structural holes can reflect the position of nodes in the network. The degree of structural holes can be judged by the structural holes index. However, when the structural constraint value is the same, it is difficult to determine which network structural position is more advantageous, while betweenness centrality can more clearly identify dominating individuals by calculating their betweenness centrality index.

Centrality in the Municipal Leadership Transfer Network. It represents the degree of centralization of the node in the network and the degree of acquisition and control of information resources (Paruchuri, 2010). Specifically, the higher centrality of the node cities, the more information and resources mastered by local officials, and the more opportunities to implement policy diffusion in our study. Among many kinds of centrality degrees, betweenness centrality exactly measures the bridging network structure (Wasserman and Faust, 1994). Actors with higher betweenness centrality have more control over

information flows in the network (Andrew and Carr, 2013). Therefore, we select betweenness centrality in our study. The betweenness centrality of one city can be expressed by the following formula (Freeman, 1982; Schilling and Phelps, 2005):

$$Municipal\ Betweenness\ Centrality_{ki}=kt\Sigma_{j<i}g_{ji}(n_k)/g_{ki} \quad (1)$$

where $g_{ji}(n_k)$ refers to the number of shortest paths between node j and node i, and g_{ji} represents the total number of shortest path lines between node j and node i. The value range of intermediary centrality is [0,1]. If the value is 0, it means that the city cannot control any other cities; if it is 1, the city can completely control other cities and is at the center of the intergovernmental network.

Then, we operationalize the leadership-transfer-weighted centrality as the following steps designed. Assume an agent to be transferred from $City_j$ to $City_i$ in $Year_t$. First, we use Pajek to calculate the betweenness centrality of each node, represented by (1). Then, we put weights into the independent variable as given in the following formula.

$$X_{bi,t}=Y_{j,t-1}\times B_{jt}\times w_t \quad (2)$$

In this formula, $X_{bi,t}$ is constructed as the independent variable. $Y_{j,t-1}$ is the lagged dependent for city-level environmental governance performance, as measured by the Environmental Pollution Index of $City_j$ in $Year_{t-1}$. $B_{j,t}$ is the betweenness centrality of $City_j$ in $Year_t$. The variable w_t represents the percentage of the transfer paths from $City_j$ to $City_i$ to all the paths transferred to $City_i$.

Structural Holes in the Municipal Leadership Transfer Network. It measures the structural degree that officials on cross-regional transfer adopt environmental policy diffusion. When the node city occupies higher structural holes, it indicates that officials in the city have more scarce information and resources, which make them more competitive. Local officials are thus more willing to embrace innovation and implement policy diffusion. To compute structural holes, we first follow equation 3 to get the dyadic constraint c_{ij} between jurisdiction i and jurisdiction j (Goyal and Vega, 2007):

$$c_{ij}=(\mathrm{pij}+\Sigma_{k,k\neq i,k\neq j}p_{ik}p_{kj})^2 \quad (3)$$

In equation 3, c_{ij} represents the extent of connectedness among jurisdictions in the two jurisdictions (Burt, 1992). Then, we sum the dyadic-level constraints to an aggregate constraint measure C_i for jurisdiction i:

$$C_i=\Sigma jc_{ij} \quad (4)$$

Next, we subtract the aggregate constraint measure C_i from 2 to represent the extent to which jurisdictions tied to a focal jurisdiction i are disconnected (Lee and Kim, 2011):

$$S_i=2\text{-}C_i \quad (5)$$

Finally, we follow the same method of putting weight as the above betweenness centrality, and we obtain formula 6 as follows. $X_{si,t}$ is another independent variable.

$$X_{si,t}=Y_{j,t-1}\times S_{j,t}\times w_t \quad (6)$$

3.4. Moderating variables

Referring to the above method of constructing independent variables, we construct provincial centrality and provincial structural holes in the provincial leadership transfer network, which are represented by $X_{pb_{i,t}}$, $X_{ps_{i,t}}$.

3.5. Control variables

We involve two types of variables: one represents the characteristic variables of the region, including the gross regional product (GRP) per capita, secondary industry percentage, economic openness, and the growth rate of GRP; the other represents the characteristic of officials, including their age, education, gender, tenure, original positions of incumbents, and departure of predecessors. All the above variables were collected from the *China City Statistical Yearbook* and the Local Leaders Database.

3.6. Analysis methods

Although mainstream innovation diffusion research still uses discrete-time event history analysis, it does not control the time factor. Some scholars have expressed concern about the practice of not controlling the time factor in the event history model (Steffensmeier, 1997). To test our hypothesis, we construct a continuous performance variable of policy diffusion, and estimate panel models with fixed effects both for the cities and years, as well as two-way cluster-robust standard errors. We develop three distinct models for each of our performance outcomes.

Based on Aiken *et al*. (1991) and Haans *et al*. (2016), we estimate the following model for city *i* in year t:

$$Y_{i,t}=\beta_0+\beta_1 X_b+\beta_2 X_s+\beta_3 X_b^2+\beta_4 X_s^2+\beta_5 X_b X_{pb}+\beta_6 X_b^2 X_{pb}+\beta_7 X_s X_{ps}+\beta_8 X_s^2 X_{ps}+\beta_c Controls_{i,t}+T_t+\varepsilon_{i,t}$$

To test H1 and H2, we must examine β_1, β_2, β_3, and β_4. H1 suggests an inverted U-shaped relationship between municipal centrality in the leadership transfer network and performance of environmental policy diffusion, requiring $\beta_1>0$ and $\beta_3<0$. H2 indicates an inverted U-shaped relationship between municipal structural holes and the performance of environmental policy diffusion, requiring $\beta_2>0$ and $\beta_4<0$. To test H3 and H4, we need to examine β_6 and β_8. When β_6 and β_8 are significant and positive, the inverted U-shaped curve flattens. While β_6 and β_8 are significant and negative, the inverted U-shaped curve steepens.

4. Results

4.1. Testing the direct effect

The descriptive statistics are displayed in Table 1. Table 2 displays the Pearson correlations among variables. The regression findings are shown in Table 3. Each variable's variance inflation factor (VIF) was assessed, and all VIF values were less than 5. The error terms were subjected to a variety of tests to determine whether they were independent and distributed normally.

In Model 1, variables from the characteristics of officials and regional features were included to estimate environmental governance performance. This step was to see whether adding network structural indicators to the findings altered their resilience to the impacts of the abovementioned variables. Model 1 found a positive and statistically significant coefficient for the GRP growth rate and party chiefs' gender. In addition, GRP per capita in the leadership transfer network was negative and significant, which indicated that GRP per capita progress will block environmental governance performance. From an overall view, the GRP growth rate was shown to be statistically significant and positive in environmental pollution performance across all three models at the 0.01 level, indicating that economic growth often comes at the expense of environmental quality, while secondary industry percentage was found to be statistically significant and negative across all models. This means that governments have begun to pay increasing attention to environmental governance with the enhancement of economic strength, which is in line with our current national conditions. Some officials' characteristic variables were also found to

Table 1
Descriptive statistics.

Variables	N	Mean	SD	Min	Max
EPI (logged)	4,209	1.864	0.909	-1.609	4.257
Municipal centrality	4,209	0.005	0.042	0	1.175
Municipal structural holes	4,209	7.413	26.010	0	642.000
Provincial centrality	4,209	0.323	0.987	0	8.558
Provincial structural holes	4,209	22.650	27.780	0	119.000
Age_PC	4,195	52.580	3.826	23.000	63.000
Gender_PC	4,195	0.966	0.181	0	1.000
Education_PC	4,195	1.926	0.745	0	3.000
PredP_PC	4,195	0.271	0.444	0	1.000
Tenure_PC	4,209	2.725	1.642	1.000	11.000
OrigP_PC	4,209	0.861	0.346	0	1.000
Age_Mayor	4,196	50.450	3.936	32.000	61.000
Gender_Mayor	4,196	0.949	0.221	0	1.000
Education_Mayor	4,196	1.977	0.723	0	3.000
PredP_Mayor	4,196	0.437	0.496	0	1.000
Tenure_Mayor	4,209	2.509	1.459	1.000	12.000
OrigP_Mayor	4,209	0.928	0.258	0	1.000
GRP Growth Rate	4,207	11.430	4.903	-19.380	109.000
Secondary Industry	4,209	48.200	11.170	0	90.970
Openness	4,202	0.020	0.026	0	0.773
Per Capita GRP	4,192	10.230	0.807	4.595	15.680

make a difference. The gender of the party chief was statistically significant at the 0.01 level. The age of the mayor was significant in the last model but insignificant in the first two models. Although officials' gender was statistically significant and positive in environmental pollution performance across all three models, the results do not support the impact on environmental governance since 97% of officials are male. The effects of officials' educational experience and official position before and after transferring were insignificant across all the models, suggesting that officials are more susceptible to environmental influences in implementing policy innovations.

In Model 2, network structural indicators were added to the statistical regression. This model tests H1 by regressing the environmental pollution index on the centrality and structural holes in the leadership transfer network, their squared terms, and other control variables. The results displayed that municipal centrality had a statistically significant and positive effect on the environmental pollution index at the 0.01 level, suggesting that officials transferred from other cities in the municipal leadership transfer network led to a higher environmental pollution index. The negative significance of the squared municipal centrality indicates that the positive impact of municipal centrality in the leadership network on the environmental pollution index is diminishing. Figure 3 presents an inverted U-shaped relationship between municipal centrality in the leadership network and the environmental pollution index. The curve

Table 2
Correlation matrix.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Environmental Pollution Index	1.000																			
2. Municipal structural holes	0.134***	1.000																		
3. Provincial structural holes	-0.046**	-0.002	1.000																	
4. Municipal centrality	0.091***	0.205***	0.026*	1.000																
5. Provincial structural holes	-0.086***	0.010	0.475***	0.016	1.000															
6. GRP Growth Rate	0.081***	-0.096***	-0.234***	-0.092***	-0.255***	1.000														
7. Openness	0.138***	0.063***	-0.006	0.043***	0.106***	0.046***	1.000													
8. Age_PS	0.045***	0.079***	0.178***	0.069***	0.128***	-0.157***	0.026*	1.000												
9. Gender_PS	0.040***	-0.001	-0.001	-0.006	0.007	0.047***	-0.029*	0.048***	1.000											
10. Education_PS	-0.027*	0.059***	0.077***	0.062***	0.045***	-0.114***	0.023	-0.266***	-0.028*	1.000										
11. PredP_PS	0.048***	-0.018	-0.047***	0.002	-0.002	0.031**	0.054***	-0.017	-0.001	0.021	1.000									
12. Tenure_PS	0.019	-0.024	-0.036**	-0.048***	-0.090***	0.102***	0.027*	0.195***	0.036**	-0.077***	0.038**	1.000								
13. OrigP_PS	-0.079***	-0.099***	-0.034**	0.000	-0.012	0.037**	-0.079***	-0.121***	-0.064***	-0.002	-0.012	0.026*	1.000							
14. Age_Mayor	0.113***	0.135***	0.122***	0.075***	0.120***	-0.174***	0.111***	0.109***	0.009***	0.067***	0.071***	0.061***	-0.115***	1.000						
15. Gender_Mayor	0.038**	0.020	-0.043***	0.020	0.000	0.022	0.006	0.004	-0.020	-0.010	-0.009	0.007	-0.034**	0.084***	1.000					
16. Education_Mayor	-0.041***	0.042***	0.107***	0.066***	0.028*	-0.106***	-0.035**	0.052***	-0.017	0.088***	-0.018	-0.038**	0.006	-0.235***	0.002	1.000				
17. PredP_Mayor	0.031**	-0.078***	0.075***	-0.052***	0.018	0.038**	-0.005	-0.048***	-0.014	-0.001	-0.013	-0.199***	0.172***	-0.003	-0.073***	-0.006	1.000			
18. Tenure_Mayor	0.046***	0.010	-0.014	-0.017	-0.081***	0.076***	0.036**	0.071***	0.038**	-0.015	0.019	0.310***	-0.061***	0.227***	0.008	-0.068***	0.016	1.000		
19. OrigP_Mayor	-0.083***	-0.140***	-0.024	-0.036**	0.017	0.008	-0.098***	-0.073***	-0.002	0.006	-0.025	-0.026*	0.201***	-0.147***	-0.027*	-0.009	0.079***	0.063***	1.000	
20. Per Capita GRP	0.155***	0.223***	0.320***	0.178***	0.204***	-0.338***	0.200***	0.227***	-0.045***	0.143***	0.061***	-0.031**	-0.137***	0.237***	-0.039**	0.113***	0.035**	0.019	-0.139***	1.000
21. Secondary Industry	0.176***	0.026*	0.085***	-0.039**	-0.080***	0.144***	0.038**	0.030**	-0.028*	-0.045***	0.006	0.046***	0.032**	-0.031**	-0.057***	-0.026*	0.134***	0.040***	0.050***	0.341***

Note: *** p<0.01, ** p<0.05, *p<0.1 (two-tailed)

Table 3
Regression results for policy diffusion.

DV:	Model 1	Model 2	Model 3
Municipal centrality		0.085***(4.820)	0.088***(4.765)
Municipal centrality2		-0.003***(-3.887)	-0.004***(-3.918)
Municipal structural holes		0.053*(1.844)	0.082**(2.432)
Municipal structural holes2		-0.002*(-1.860)	-0.023*(-1.888)
Provincial centrality			-0.063***(-6.453)
Municipal centrality * Provincial centrality			0.022(0.805)
Municipal centrality2 *Provincial centrality			-0.004*(-1.815)
Provincial structural holes			0.019(1.503)
Municipal structural holes * Provincial structural holes			0.027(0.953)
Municipal structural holes2 * Provincial structural holes			-0.025*(-1.719)
GRP Growth Rate	0.009***(4.757)	0.009***(4.573)	0.008***(4.167)
Openness	-0.030(-0.081)	0.035(0.096)	0.498(1.344)
Age_PC	0.004(1.642)	0.004(1.514)	0.004*(1.730)
Gender_PC	0.155***(3.336)	0.152***(3.270)	0.151***(3.282)
Education_PC	-0.008(-0.648)	-0.009(-0.743)	-0.008(-0.639)
PredP_PC	0.001(0.068)	0.006(0.281)	0.007(0.372)
Tenure_PC	-0.007(-1.273)	-0.004(-0.749)	-0.005(-0.893)
OrigP_PC	0.023(0.867)	0.023(0.853)	0.031(1.157)
Age_Mayor	0.004(1.560)	0.003(1.367)	0.005*(1.843)
Gender_Mayor	0.012(0.310)	0.010(0.265)	0.010(0.256)
Education_Mayor	-0.006(-0.487)	-0.010(-0.802)	-0.010(-0.778)
PredP_Mayor	0.024(1.315)	0.030(1.605)	0.026(1.405)
Tenure_Mayor	0.009(1.503)	0.009(1.560)	0.006(1.081)
OrigP_Mayor	0.055(1.530)	0.060*(1.687)	0.072**(2.021)
Per Capita GRP	-0.194***(-11.226)	-0.219***(-12.115)	-0.204***(-10.527)
Secondary Industry Percentage	-0.010***(-6.500)	-0.008***(-5.332)	-0.010***(-6.504)
Constant	3.567***(15.250)	3.791***(15.948)	3.644***(14.499)
Observations	4,164	4,164	4,164
R-squared	0.097	0.105	0.117
Number	292	292	292

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

reaches a turning point when municipal centrality in the leadership network is equal to 0.54, suggesting that an official transferred from another city starts to value environmental issues when its centrality approaches around one-third of the maximum. Thus, H1 is supported.

Similarly, Model 2 also reports the municipal structural holes' coefficient is positive and significant, but a negative and significant coefficient for squared municipal structural holes at the 0.1 level, consistent with H2. Figure 4 shows that the structural holes in the municipal leadership transfer network have

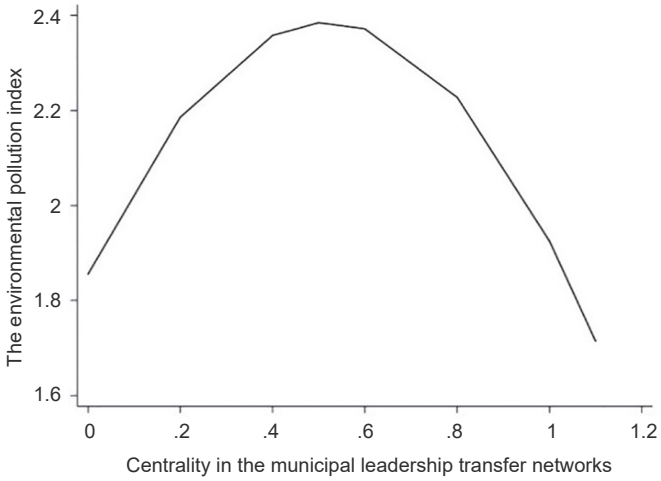

Fig. 3. The relationship between centrality in the municipal leadership network and the environmental pollution index.

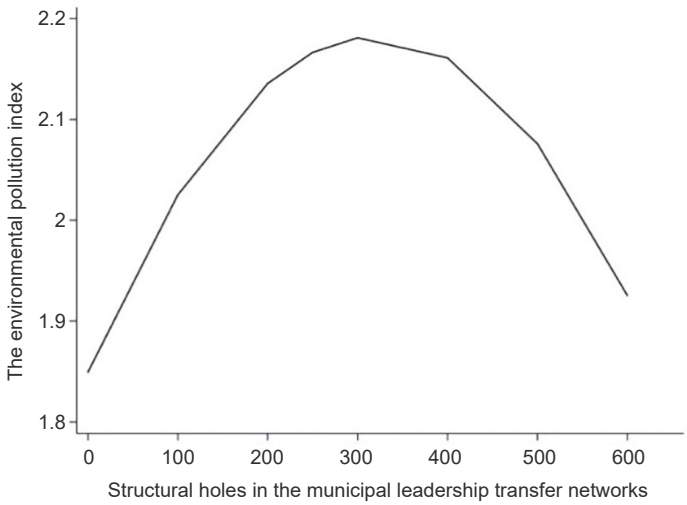

Fig. 4. The relationship between structural holes in the municipal leadership network and the environmental pollution index.

an inverted U-shaped relationship with the environmental pollution index. The results for the control variables remain stable, with similar coefficients to those in Model 1. This implies that the inclusion of network structure indicators, as well as their importance, does not negate the influence of the control variables.

4.2. Testing the moderating effect

In Model 3, the results imply that provincial centrality and structural holes have statistically significant and positive interaction effects with municipal indicators on the environmental pollution index. To ascertain how provincial network indicators moderate Model 2, we analyzed the regression coefficient. The coefficient of the interaction term between the squared municipal centrality and provincial centrality solely determines whether the inverted U-shaped relationship is flattening or steepening. Since,

in our study, the coefficient of β_6 is -0.004, we conclude that the inverted U-shaped curve between the municipal centrality and environmental pollution index steepens with increasing provincial centrality in Figure 5. Specifically, provinces with high centrality strengthen the positive latent mechanism through municipal centrality influences on environmental pollution performance. Similarly, the coefficient of β_8 is -0.025, which means provincial structural holes also strengthen the positive performance, through which municipal structural holes affect the environmental pollution index in Figure 6. Thus, H3 and H4 are supported.

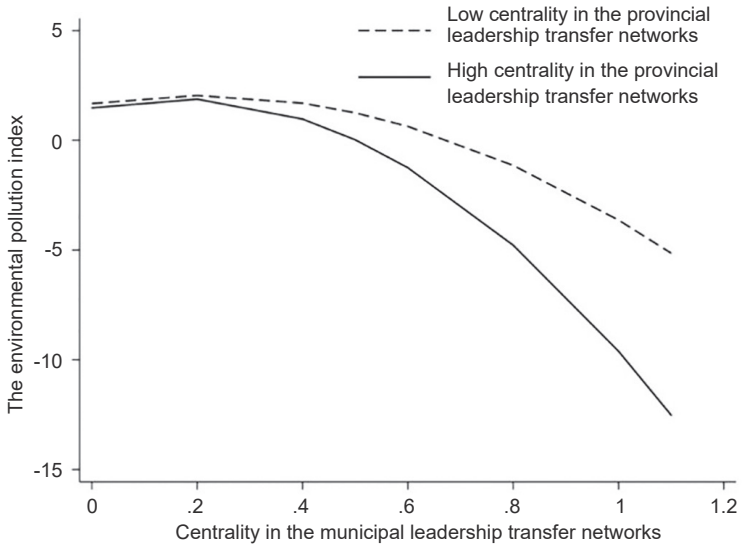

Fig. 5. The moderating effect of provincial centrality.

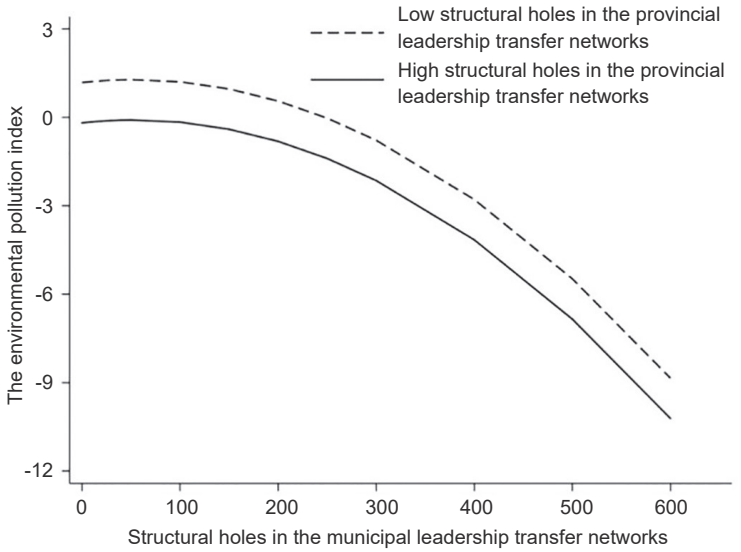

Fig. 6. The moderating effect of provincial structural holes.

5. Discussion and Conclusion

5.1. Discussion

According to the regression results, the coefficients for centrality and structural holes in leadership transfer networks are statistically significant. It shows that leadership transfer networks provide a channel for policy diffusion, and their structures have some impact on policy diffusion. Our selection of policy diffusion in the environmental domain compels the inclusion of economic development in the discussion of the study.

In China, environmental governance and economic development are a pair of reverse political tasks for officials. Scholars have studied the trade-off process between environmental governance and economic development. This process depends on the officials' political motivations, which are influenced by the Chinese cadre evaluation system and policy signals from higher levels of governments. However, with the improvement of the official assessment system and increasing emphasis on environmental governance, officials have to balance their achievements in various aspects. Thus, they have to take each policy diffusion seriously from a systemic and holistic perspective.

In our study, the centrality and structural holes of leadership transfer networks comprehensively represent the information resources and competitive advantages to local officials. The impact of these two indicators on environmental governance performance is illustrated in Figures 3 and 4. And Model 2 reveals that officials consider their own career development much more than regional governance when they are "nobody" (low centrality and structural holes). On the one hand, they are politically motivated by the goal of economic growth to achieve promotion and thus gain more status and power. On the other hand, they have scarce resources and low power to implement and control the governance of their jurisdictions. Once they reach a certain level of status and power (the turning point in the Figures 3 and 4), they begin to break through to new development opportunities. And sufficiently high level of network centrality and structural holes enhance their heterogeneous capabilities, and motivates them to extend their political motivation beyond their own development to regional governance, which is of particular central importance. Thus, as the structure indicators of leadership transfer network continue to rise, jurisdictions' environmental governance increases from an initial surrender to a subsequent strengthening, and the environmental pollution index tends to rise and then fall.

However, when we include some corresponding structural indicators of the provincial leadership transfer network in our study, the main models change from the original inverted U-shape to the steeper curves in Figures 5 and 6, and tend to be negatively linearly correlated. The steeper curves suggest that top-level government support can strengthen the implementation of policy goals by lower-level governments, which validates the top-down support's facilitative effect on policy diffusion in previous studies. But it is worth mentioning that the adjusted curves show a negative linear correlation. We trace back to the central-territory relationship in China, which is a vertical distribution of power and resources, where lower-level governments are bound by higher-level governments. In this case, the provincial moderating variable significantly influences the above negative mechanism contained in the inverted U-shape relationship. At the same time, Figures 5 and 6 show that the will of higher-level officials affect the choice of political motivation of lower-level officials, and that this impact is much greater than the impact of lower-level officials' own network structure on policy diffusion. Even if lower-level officials do not have sufficient resources and ability to implement policy innovations and diffusion, they can rely on the resources of higher-level governments and adhere to the will of higher-level officials to implement

policy innovations. One is for the sake of administrative orders issued by the higher government, and the other is to greatly reduce the risk of implemented policy innovations and diffusion.

In addition, we carry out the following robustness checks to test the stability and reliability of the inverted U-shaped relationship between the municipal leadership transfer network structure and environmental pollution performance. Firstly, add the third term of municipal centrality and municipal structural holes into the Model 2. The result shows that coefficients of the third term of municipal centrality and municipal structural holes are not statistically significant ($p>0.1$), which indicates the existing inverted U-shaped curves can better fit our data. Secondly, based on the testing process proposed by Aiken and West, we separately test the significance of the regression coefficients of samples with high network structure and low network structure (that is, the positive and negative parts of the inverted U-shaped curve). We take the network structure indicators of the turning point of the inverted U curve below one standard deviation and above as the samples of low centrality and high centrality respectively, and conduct regression analysis. The results show that for low network structure samples, the regression coefficient is significantly positive; for high network structure samples, the regression coefficient is significantly negative. All the above tests prove that our results are robust.

5.2. Conclusion

This study has explored the effects of the leadership transfer network structure on the performance of environmental policy diffusion. By regression analysis, we verified the hypothesis that municipal centrality and municipal structural holes in the municipal leadership transfer network have an inverted U-shaped relationship with the environmental pollution index. Furthermore, provincial centrality and provincial structure moderate the double inverted U-shaped relationship in such a way that the curves are steeper in cities with high provincial centrality or provincial structural holes than in cities with low provincial centrality or provincial structural holes.

This study adds to the diffusion literature by expanding the practice of policy diffusion using social network analysis. Most previous research on policy diffusion focuses on the diffusion mechanism and its corresponding empirical tests. The emerging research has begun using the social network analysis method to describe policy diffusion through the overall characteristics of networks. Research on how network structure indicators affect policy diffusion is widely ignored. However, network structure as a perspective is more consistent with contemporary theoretical viewpoints, which see policy diffusion processes as complex systems requiring investigation of their interdependent relationships rather than their independent components. As a result, the social network analysis method is required to elucidate the effect of relationship network structure on policy diffusion.

This study also provides a cross-layer perspective to broaden the research of policy diffusion, systematically exploring the moderating impact of provincial governments on municipal governments in the diffusion process. Since China is featured as a multilevel government, most policy directives are issued at a hierarchical level (central-provincial-municipal) and the bottom governments are responsible for implementation. This study advances a multilevel system by embedding the moderating roles of provincial leadership transfer networks.

This study can also make many recommendations for public administration practice. The findings of this research may aid policymakers in better understanding the relationship between policy network structure and policy diffusion. To improve the efficiency of environmental governance, policy actors can also proactively increase external links and cluster close allies together.

A few limitations should be refined in further study. This study used the leadership transfer network to test the impact of network structure on policy diffusion, which is not the sole channel for information diffusion. This study did not capture essential network management aspects, such as networking tactics, connecting details, and communication skills. Additional research is necessary to conceive, quantify, and test the effect of leadership transfer networks on policy diffusion. Furthermore, the cooperation networks formed with other related organizations are also worthy of embedded research to simultaneously investigate both the construction of the leadership transfer network and diffusion of innovation. Lastly, around the world, different systems in different countries may yet influence the process of policy diffusion. This study has involved Chinese data from all municipality and provinces as great as possible, but if we want to explore the impact of social network structure on the policy diffusion more accurately and deeply, we had better select different countries as a sample to reduce statistical errors. And future studies will overcome the difficulty of sampling, and expand the sample to enhance the persuasion of the study.

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