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Influencing Factors Analysis of the Development of Geothermal Energy Industry, a Case Study of Beijing, China

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ABSTRACT

Rapid urbanization has resulted in severe demands on water, heat and energy resources, which threaten the sustainability of the urban economy and environment. Geothermal energy is one of the cleanest sources of energy and it plays an important role in the sustainability of the urban economy and environment. This paper employs Vector Autoregressive Model (VAR) model to detect the effects of water, heat and energy consumption on geothermal adoption and interactions among them. Beijing is chosen as a case study to investigate the water-heat-energy nexus and coupling coordination between geothermal adoption and regional economy. The results reveal that water consumption has mainly affected on geothermal adoption. Water consumption and energy consumption have negative effects on geothermal adoption while centralized heat supply has a positive effect on geothermal adoption. This paper also adopts gear model to investigate coupling coordination between geothermal adoption and regional economy. The rates of geothermal adoption and regional economy are various but they are in the good state of coupling coordination. In addition, the coupling coordination of geothermal adoption and regional economy has the potential to promote.

1. INTRODUCTION

Energy consumption continues to increase, and environmental problems have become increasingly more prominent with the rapid development of China's economy (Fan and Lei, 2015). China announced its goal to reach its carbon emissions reduction peak in approximately 2030, with the intention to peak earlier and to raise the non-fossil fuel share of its primary energy supply to approximately 20% by 2030 (Xinhuanet, 2014). Beijing should be responsible for mitigating and adapting to climate change, since it is China's capital and its political and cultural centre (Zhong et al. 2017). The utilization of geothermal energy is a better choice in Beijing in order to meet the growing demand for energy and mitigate climate change.

To guarantee increased geothermal adoption, the Beijing municipal government formulated a series of policies and regulations. In 2011, the Beijing municipal government stated that increased geothermal adoption is an essential target in promoting “Green Beijing”, which was proposed in the development plan for new energy and renewable energy in Beijing’s 12th Five-Year Plan. The Beijing Municipal Commission of Development and Reform, along with 6 bureaus, issued a document on the “guidelines on further promoting the development of geothermal energy and the implementation of heat pump systems in Beijing” in December 2013. This document explicitly stated that enterprises could get 50% government subsidies for their heating when they drill geothermal wells, and the heating projects could get 30% government subsidies for using shallow geothermal energy. The National Development and Reform Commission, the National Energy Administration and the Ministry of Land and Resources jointly issued a document called the “Thirteenth Five-Year Plan of Geothermal Energy Development and Utilization” in January 2017, which explicitly stated that the scale of the area for shallow geothermal heating (cooling) will be increased to 700 km2, and the scale of the area for hydrothermal geothermal heating will be increased to 400 km2 in 2020 (Jiang, 2016; Jiang, 2019).

Beijing is rich in low-temperature geothermal energy with 10 geothermal fields with a total area over 2760 km2 (Liu et al., 2010). The temperature of geothermal water is 25℃ to 89℃. Geothermal energy has been used for space heating, bathing, greenhouses and so on for nearly 40 years, and this type of energy has a great effect on regional social and economic benefits (Wang, 2007). However, energy restrictions in Beijing have gradually become a bottleneck that restricts regional economic and social development. To better implement geothermal adoption, the contributions of the factors influencing geothermal adoption in Beijing, including the water consumption, centralized heat supply and energy consumption, should be explored. Furthermore, it is necessary to explore the variance in the coupling coordination degree between geothermal adoption and Beijing’s economy in order to promote the sustainability of geothermal resources.

In the geothermal system, it requires water and energy, and water and energy consumption produce heating for the centralized heating areas. In the current studies, there are three elements were studied separately for geothermal adoption system. To make water, heat and energy involved in systematic management, researchers have worked on interpreting the nexus of water, heat and energy respectively. In this study, the water-heat-energy nexus was defined as the relationship among water consumption, centralized heat supply and energy consumption in the system of geothermal adoption. Heat is focusing on the district heating system through power system, which can give heat to the buildings. Energy refers to the power system which includes coal, gas, electricity and other renewable sources. In the system of geothermal adoption, the heat pumps should use the energy such as electricity or hot water to generate the heat. The present study is concerned with geothermal adoption, which is coupled with the regional economy. The remainder of this paper is organized as follows. Section 2 presents a review of the relevant literature. Section 3 introduces the study’s methodology and data sources. Section 4 discusses the results and analysis. The conclusions and policy implications are presented in Section 5.

2. LITERATURE REVIEW

Water-energy nexus studies have focused on the relationship between water and energy and its effects on the environment, climate change and social development. Wang et al. (2017) discussed water and electricity consumption in the process of coking, sintering, iron making, steel making and rolling in China's steel industry. Mo et al. (2014) studied how water consumption impacted energy use and climate change. They found the importance of assessing the energy–water nexus for enhanced water supply scenarios. Yang and Chen (2016) applied a new energy–water nexus analysis framework for wind power generation systems in order to investigate the relationships between the pairwise components of wind power generation systems. Mroczek et al. (2017) described the water consumption in geothermal fields and assessed the potential risks of the injection of geothermal water. Daniilidis et al. (2017) designed a model predictive control strategy to measure the geothermal water and energy consumption in the heat production of a geothermal system in order to couple the heat networks and achieve sustainable geothermal adoption.

With respect to the water-heat nexus, it is vital to coordinate the heat supply and water consumption in the heating systems, and the geothermal water must be adjusted to match the seasonal changes (Eicker et al., 2015; Sayegh et al., 2016; Kyriakis and Younger, 2016). However, water consumption and geothermal water flows can affect geothermal heat production. In geothermal heating systems, there are several related influencing factors such as the recycling heat transmission fluid and geothermal exploitation. Cui et al. (2017) and Bu et al. (2012) proposed a method for geothermal exploitation in order to calculate the heat mining rate and the relationship between the geothermal water and heat production. With respect geothermal power generation, Cheng et al. (2014) analysed the heat production from geothermal water flows using heat exchangers. Aliyu et al. (2017) applied an approach for the long-term development of geothermal heating production. They found that the geothermal water temperature is the parameter that influences the geothermal heating system.

Previous research has focused on the energy and heat nexus. Lomas et al. (2018) showed that the energy savings of most heating controls depend strongly on variable situations that the heating system is operated with a continuous or periodic heating pattern, as well as on the energy efficiency of the dwelling and the severity of the climate. Some researchers have tried to make inferences about the energy savings from heating controls. Kelly et al. (2013), Shipworth et al. (2010) and Shipworth (2011) used temperature data in order to assess thermostat use, but no direct evidence of energy savings was provided. Zeng et al. (2017) focused on the coordinated operation of the electricity, gas and district heating systems in urban areas where multi-energy systems belong to a single entity. Taleghani et al. (2019) adopted a computational fluid dynamics model in order to analyse the effects of heat mitigation strategies on the surface energy balance at the neighbourhood scale. Kwon et al. (2012) and Zhu et al. (2014) evaluated how energy performance affected heating systems. Park et al. (2018) developed a predictive model using an artificial neural network (ANN) in order to forecast the energy costs for heating systems. For the geothermal industry in particular, research has focused on the sustainability of geothermal heating systems. Sam et al. (2015) applied an economic model in order to analyse the effects of finances on geothermal adoption. Zhou et al. (2014) clarified the composition of the geothermal sector using the technological processes for the exploitation and utilization of geothermal energy, which is related to water consumption. Shortall et al. (2015) described the assessment framework for geothermal projects in Iceland, New Zealand and Kenya. However, the relationships among the water consumption, heat supply and energy consumption in specific processes and in the entire geothermal industry are not yet well understood.

What are the heat supply, energy and water consumption in a geothermal heating system and how do the heat supply, water use and energy supply influence geothermal adoption? Based on the literature review, to the best of the authors' knowledge, there are no studies on the influencing factors of geothermal adoption and the coupling coordination analysis between geothermal adoption and the regional economy. The main objective of this study is therefore to evaluate the influencing factors of geothermal adoption in Beijing using the water-heat-energy nexus model and to adopt the gear model to assess the coupling coordination between geothermal adoption and the regional economy using Beijing as a case study.

3. METHODOLOGY AND DATA SOURCES

3.1 VAR model

The vector autoregressive (VAR) model (Sim 1980) generalizes the univariate autoregressive model to the multivariate case. This provides beneficial features such as the estimation of the dynamic interrelation between variables and indifference to the choice of dependent variables (Brahmasrene et al. 2014 and Han et al. 2017).

The mathematical representation of the VAR model is as follows:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + Bx_t + \varepsilon_t + C \quad t=1, 2, \ldots, T \tag{1}$$

where T is a K×1 time-series vector, and A is a K×K parametric matrix. Xt is an M×1 vector of exogenous variables, and B is a K×M coefficient matrix that is to be estimated. Ɛt represents the random error term, and C is a constant term.

In formula (1), the endogenous variable has a lag period (p); thus, the formula can be called a VAR (p) model, which can fully reflect the dynamic characteristics of the constructed model. When the Swartz Criterion (SC) and Akaike information criterion (AIC) are the lowest, we get suitable lag periods. The formulas of these two statistics are expressed as follows:

$$AIC = -\frac{2l}{n} + \frac{2k}{n} \tag{2}$$

$$SC = -\frac{2l}{n} + k\frac{\ln n}{n} \tag{3}$$

where k = m (qd + pm) represents the number of parameters to be estimated. n is the sample size, and it meets the following formula:

$$1 = -nm(1+\ln 2\pi)/2 - n\ln\left[\det\left(\sum_t \hat{\varepsilon}_t \varepsilon_t' / n\right)\right]/2 \tag{4}$$

3.2 Gear Model

This paper uses the mechanics of the gear transmission principle to analyse the relationship between the geothermal industry and the regional economy. As shown in Figure 1, there are three meshing gears in mechanics (Zhao et al., 2017).

Gear 1 represents the geothermal industry, Gear 2 represents the regional economy, and Gear 3 represents the other industries in the economy. The rotation of Gear 1 drives the rotation of Gear 2, while the rotation of Gear 3 drives the rotation of Gear 2. Whether gears rotate faster or slower depends on the number of teeth on the basic wheels. The meshing rotation relationship of Gear 1 and Gear 2 is similar to the interaction between the regional economy and the geothermal industry to promote each other. The gear model can illustrate this dynamic process of the development of geothermal adoption. The gear ratio i refers to the ratio of the speed of Gear 1 and Gear 2. The formula is as follows:

$$i = w_1 / w_2 = z_2 / z_1 \tag{5}$$

where w1 is the angular velocity of Gear 1, which is the speed of geothermal development; w2 is the angular velocity of Gear 2, which is the speed of regional economic development; z1 is the number of teeth on Gear 1; and z2 is the number of teeth on Gear 2.

According to the principle of gear transmission, the speed increases after the linked operation between Gear 1 and Gear 2. The total speed of Gear 1 is set to Δω1, and the speed of Gear 2 is increased by Δω2. The final speed of Gear 1 is V1 = ω1 + Δω1. The speed of Gear 2 is as follows.

$$V_2 = (z_1 / z_2) \times (\omega_1 + \Delta\omega_1) \tag{6}$$

$$\Delta\omega_2 = (z_1 / z_2) \times \Delta\omega_1 \tag{7}$$

$$T = \Delta\omega_1 / \Delta\omega_2 = z_2 / z_1 \tag{8}$$

where T is the ratio of development between geothermal adoption and the regional economy. Δω1 and Δω2 are the rates of development of geothermal adoption and the regional economy, respectively.

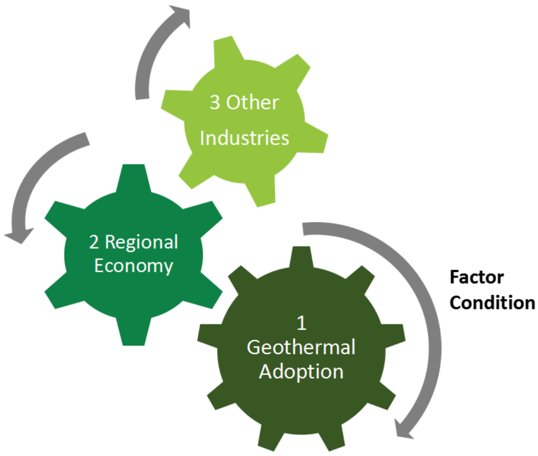

Figure 1: Gear model

3.3 Coupling coordination degree model

The coupling coordination model is obtained based on the concept and coefficient model of capacity coupling in physics (Wang et al., 2017). This coupling system incorporates two subsystems, i.e., the geothermal subsystem and the economic subsystem. The coupling coordination degree model can identify the coupling and coordination assessment between the geothermal subsystem and the economic subsystem. The computational formula is as follows.

$$D = \left\{ \frac{R_{GA} \times R_{RE}}{\left(\frac{R_{GA} + R_{RE}}{2} \right)^2} \right\}^k \tag{9}$$

where D is the system coupling coordination degree, and RGA and RRE are the rates of development of geothermal adoption and regional economy, respectively. The higher D is, the higher the coupling coordination degree between the systems. This paper adopts the max-min normalization method to standardize the data in the range of 0 to 1. The system has two subsystems, which means that k is 1/2.

3.4 Data sources

This study is based on the years from 2001-2015. The data regarding geothermal water exploitation mainly come from the Beijing Geothermal Research Institute, and the data on the water consumption, centralized heat supply, energy consumption, GDP and GDP per capita in Beijing come from the Beijing Statistical Yearbooks of 2001-2015 (Table 1). The independent variable is geothermal adoption(Y) while W is water consumption; H is heat; E is energy consumption as variables. To eliminate the heteroscedasticity that may exist in the model and to facilitate hypothesis testing, we take the logarithms of geothermal adoption, water, heat and energy, which are represented as Y, W, H and E, respectively.

Table 1: Geothermal adoption and influencing factors

Parameters	Geothermal adoption (Y)	Water consumption	Water (W)	Heat (H)	Energy (E)	GDP	GDP per capita
	104 m3	108 m3	m3/104 RMB	104 m2	kg/104 RMB	108 RMB	RMB
2001	873	38.9	104.91	14729	1198	3708.0	26980
2002	895	34.6	80.19	18172	1127	4315.0	30730
2003	586	35.8	71.50	25108	1062	5007.2	34777
2004	791	34.6	57.35	28150	1029	6033.2	40916
2005	772	34.5	49.50	31736	902	6969.5	45993
2006	735	34.3	42.25	34977	686	8117.8	51722
2007	906	34.8	35.34	37203	637	9846.8	60096
2008	961	35.1	31.58	42501	588	11115.0	64491
2009	912	35.5	29.92	44240	554	12153.0	66940
2010	975	35.3	24.94	46715	532	14113.6	73856
2011	946	36.0	22.13	50794	419	16251.9	81658
2012	1067	35.9	20.07	52555	399	17879.4	87475
2013	1242	36.3	18.37	54591	380	19800.8	94648
2014	1035	37.5	17.58	56786	360	21330.8	99995
2015	1037	38.3	16.60	58465	338	23014.6	106497

4. RESULTS AND DISCUSSION

4.1 Geothermal adoption

According to the survey data from 2015, there are 184 geothermal wells that have been developed and exploited in Beijing, including 149 exploited wells and 35 recirculated wells (Figure 2). Geothermal energy is mainly utilized in Changping and Chaoyang Districts with 34 wells and 49 wells, respectively. The level of exploitation has increased since 1971. Recirculation technology has become more mature since 2000. Heating and hot springs are the two main modes of utilizing geothermal energy (Liu and Lei, 2016).

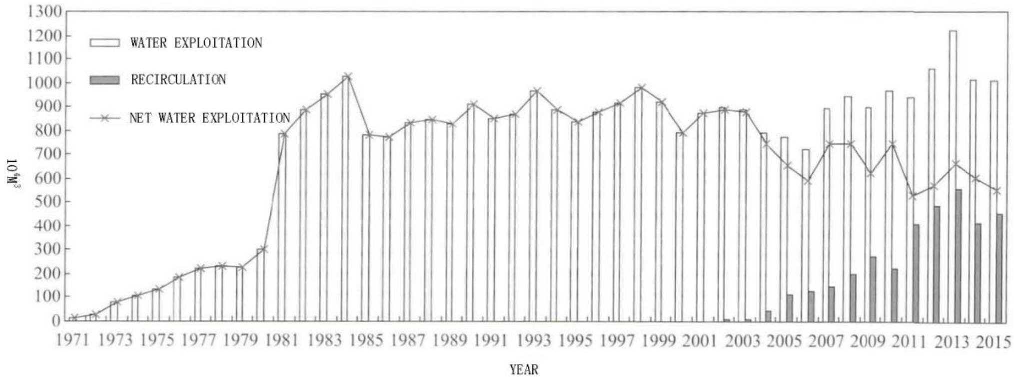

Figure 2: Beijing's net geothermal energy production from 1971 to 2015

Geothermal exploration in Beijing began in the mid-20th century in the southeast part of the city (Liu and Lei, 2016). As shown in Table 1, 504 geothermal wells had been drilled by the end of 2015, one with a depth of over 3500 m (Table 2). The temperature of the return water is approximately 25–38℃. Due to the increasing demands for geothermal heat, geothermal energy has long been overexploited and the water levels have declined (Che, 2004). Geothermal water injection has been conducted since 2001 to alleviate the water level decreases (Pan, 2010). Since 2005, the water level in the geothermal reservoir has begun to gradually recover (Duan et al., 2011).

Table 2: Summary table of Beijing's geothermal exploration data from 1971 to 2015 (Liu & Lei, 2016)

Year	Number of wells	Total depth (m)	Mean depth (m)	Max depth (m)
1971-1975	25	23943.96	957.76	2537.00
1976-1980	24	22341.21	930.90	2600.50
1981-1985	35	42040.62	1201.16	2605.00
1986-1990	29	31328.78	1080.31	2105.57
1991-1995	22	31159.45	1416.34	2572.00
1996-2000	75	151384.34	2108.50	3766.00
2001-2005	152	359191.94	2363.10	4051.36
2006-2010	115	369685.87	3214.65	4088.88
2011-2015	27	73600.68	2725.95	3616.00

4.2 Unit root test

This paper applies the augmented Dickey-Fuller (ADF) test to determine whether the time-series data are stationary (Fuller, 1976; Elliott et al., 1996). The Schwarz information criterion (SIC) determines the unit root test lag length (Findley, 1991). The results of the ADF unit root test are shown in Table 3, and they indicate that the variables are not all a stationary sequence. Meanwhile, their first-order difference is a stationary sequence. Therefore, geothermal adoption (Y), water consumption (W), heat (H) and energy consumption (E) are all integrated of order 1. That is, geothermal adoption, water consumption, heat and energy intensity are stationary in the first difference, and it can be conducted using a cointegration test.

Table 3: Results of the unit root test

	Variables	1% Critical value	5% Critical value	10% Critical value	t-Statistic	Prob.
Levels	Y(geothermal adoption)	-2.740613	-1.968430	-1.604392	0.220539	0.7353
	W(water consumption)	-2.740613	-1.968430	-1.604392	-10.148640	0.0000
	H(heat)	-2.792154	-1.977738	-1.602074	1.716257	0.9698
	E(energy consumption)	-2.740613	-1.968430	-1.604392	-4.623671	0.0002
First difference	Y(geothermal adoption)	-2.754993	-1.970978	-1.603693	-5.367611	0.0001
	W(water consumption)	-2.792154	-1.977738	-1.602074	-1.899733	0.0479
	H(heat)	-4.992279	-3.875302	-3.388330	-4.997906	0.0099
	E(energy consumption)	-2.754993	-1.970978	-1.603693	-1.737597	0.0281

4.3 Cointegration test

The trace statistic and maximum eigenvalue tests are used to determine whether there is a co-integration relationship. The results of the co-integration tests between Y, W, H and E are presented in Tables 4-5. They indicate that there are two equations between Y and W, H and E not only in the trace test but also in the maximum eigenvalue test. Therefore, a co-integration relationship exists between geothermal adoption and water consumption, heat and energy consumption.

Table 4: Unrestricted co-integration rank test (trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical value	Prob.**
None*	0.990559	120.3838	47.85613	0.0000
At most 1	0.951077	59.76931	29.79707	0.0000
At most 2	0.769731	20.54180	15.49471	0.0079
At most 3	0.105627	1.451224	3.841466	0.2283

The trace test indicates 1 cointegrating eqn at the 0.05 level.

*denotes rejection of the hypothesis at the 0.05 level

** MacKinnon-Haug-Michelis (1999) p-values

Table 5: Unrestricted co-integration rank test (maximum eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical value	Prob.**
None*	0.990559	60.61451	27.58434	0.0000
At most 1	0.951077	39.22751	21.13162	0.0001
At most 2	0.769731	19.09058	14.26460	0.0080
At most 3	0.105627	1.451224	3.841466	0.2283

The Max-Eigenvalue test indicates 1 cointegrating eqn at the 0.05 level.

*denotes rejection of the hypothesis at the 0.05 level

** MacKinnon-Haug-Michelis (1999) p-values

4.4 VAR model

4.4.1. Optimal Lag Order Analysis

It is necessary to select an optimal lag period for the variables in the model in order to have strong explanatory power. In this paper, a lag of 1-2 is selected as a result of the logarithmic likelihood ratio (LogL), AIC, SC, sequential modified LR test statistic (lR), FPE (final prediction error) and HQ (Hannan-Quinn) information criterion, as shown in Table 6. Hence, this paper selects a lag of 2.

Table 6: Lag selection criteria for geothermal application

Lag	LogL	LR	FPE	AIC	SC	HQ
0	60.73498	NA	1.91E-09	-8.728459	-8.554629	-8.764189
1	110.6431	61.42543*	1.22E-11	-13.9451	-13.07595	-14.12375
2	145.0197	21.15482	2.20e-12*	-16.77227*	-15.20779*	-17.09384*

* indicates the lag order that is selected by the criterion

LR: Sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

4.4.2. VAR Estimates and Stability Tests

We identify that all variables are stationary after first-order differencing, and there is a co-integration relationship between Y and W, H, and E based on the unit tests and the co-integration tests. Therefore, the VAR model can be estimated using the AIC and SC criteria. The VAR estimates are presented in Table 7. As Figure 3 shows, the VAR roots of the characteristic polynomial show that the characteristic roots are less than 1 and lie inside the unit circle. This indicates that the model satisfies the stability condition. The results of the unit-root tests and co-integration test show that the variables are stationary.

This paper can get the vector auto-regression estimates as follows:

$$\begin{pmatrix} Y \\ W \\ H \\ E \end{pmatrix} = \begin{pmatrix} -0.4106 & 0.6821 & 0.6132 & -0.7671 \\ 0.3369^{*} & 0.8538 & 0.3361 & 0.0230^{*} \\ -0.0027^{*} & -0.4684^{*} & 0.4110 & -0.0011^{*} \\ 0.1782^{*} & 1.7582 & 0.5843 & -0.1653^{*} \end{pmatrix} \times \begin{pmatrix} Y(-1) \\ W(-1) \\ H(-1) \\ E(-1) \end{pmatrix}$$

$$+ \begin{pmatrix} -0.5602^{*} & 0.0550 & -0.2518 & -0.6710 \\ -0.1256^{*} & -0.2016 & -0.5534 & 0.1669^{*} \\ 0.1607^{*} & 0.6062 & 0.3375^{*} & -0.1988^{*} \\ -0.3253^{*} & -0.4291 & -0.3796 & -0.4282^{*} \end{pmatrix} \times \begin{pmatrix} Y(-2) \\ W(-2) \\ H(-2) \\ E(-2) \end{pmatrix}$$

*P-value is less than 0.1.

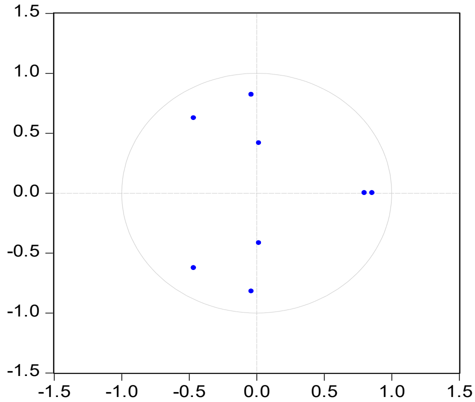

Figure 3: VAR roots of the characteristic polynomial. Note: blue dots indicate characteristic roots

4.4.3. Impulse Response Functions

As observed in Figure 4, to the response of Y, Y is mainly affected by its own historical development in the first two years, and then, Y is mainly affected by W. Y changes as the variance contribution gradually decreases from 63.11% to 31.56% from the 1st year to the 10th year. That is to say, geothermal adoption has its own historic interaction, and it fluctuates over the long term. The contribution of W to Y increases from 24.61% to 50.20% at the 5th year and then remains stable at approximately 50% from the 5th year to the 10th year. The contribution rate of E fluctuates during the years of this analysis, but the contribution rate is very small, and it becomes steady near 10%. The contribution rate of H increases from 3.09%, and it peaks at 7.42% in the 10th year. It reveals that water consumption is negatively related to geothermal adoption, while centralized heat supply is positively related to geothermal adoption. Energy consumption is negatively related in the first two years and then has a positive relationship in the third year. However, it subsequently reaches an equilibrium prior to showing a negative relationship in the long-term.

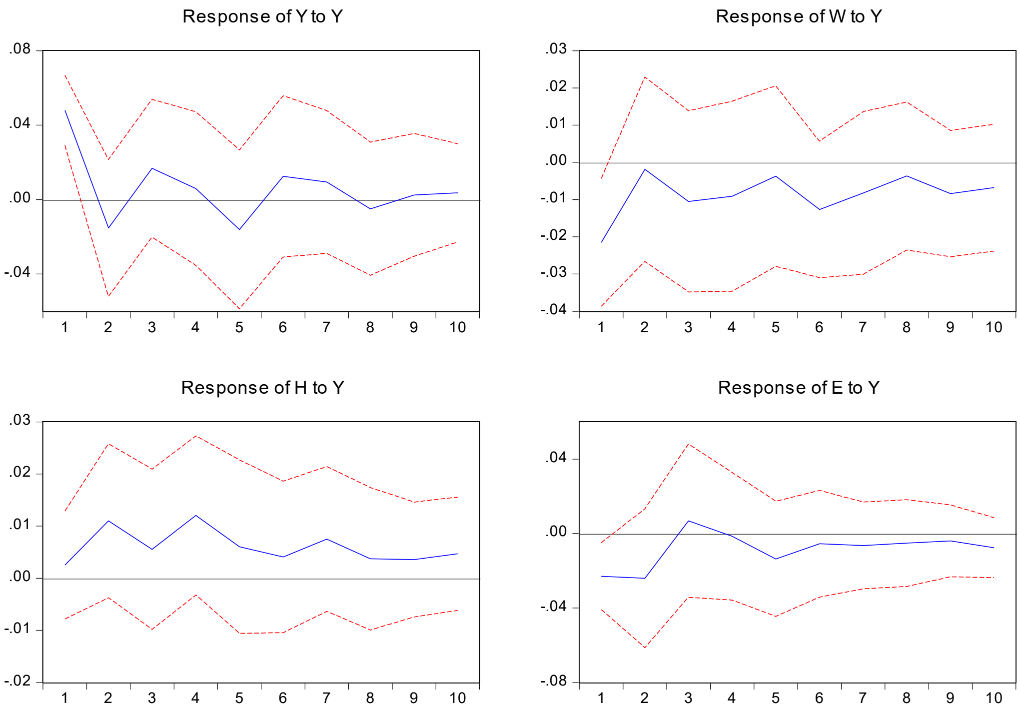

Figure 4: Responses of Y, W, H, E to Y

4.5 Gear model for improving the development of the geothermal industry

The gear model can be used to improve the coupling coordination degree between geothermal adoption and the regional economy. Water, heat and energy affect geothermal adoption. Similarly, the interactions between these factors form a joint force that can improve the geothermal industry. A gear model is developed in order to highlight this process. During the improvement process, the main force comes from the geothermal industry and three factors motivate and support the development of the geothermal industry.

4.6 Coupling coordination degree between geothermal adoption and the regional economy

The degree of coordinated coupling between geothermal adoption and the economy in Beijing followed an overall increasing trend from 1979 to 2015. The degrees are over 0.5, which shows that the development of geothermal adoption was well coordinated with the economic development in Beijing (Figure 5). The effects of the rates on the development of geothermal adoption and the economy in Beijing fluctuate around approximately 0. The average of the rates is 0.2432, which reflects that the development of geothermal adoption is positively related to the regional economy.

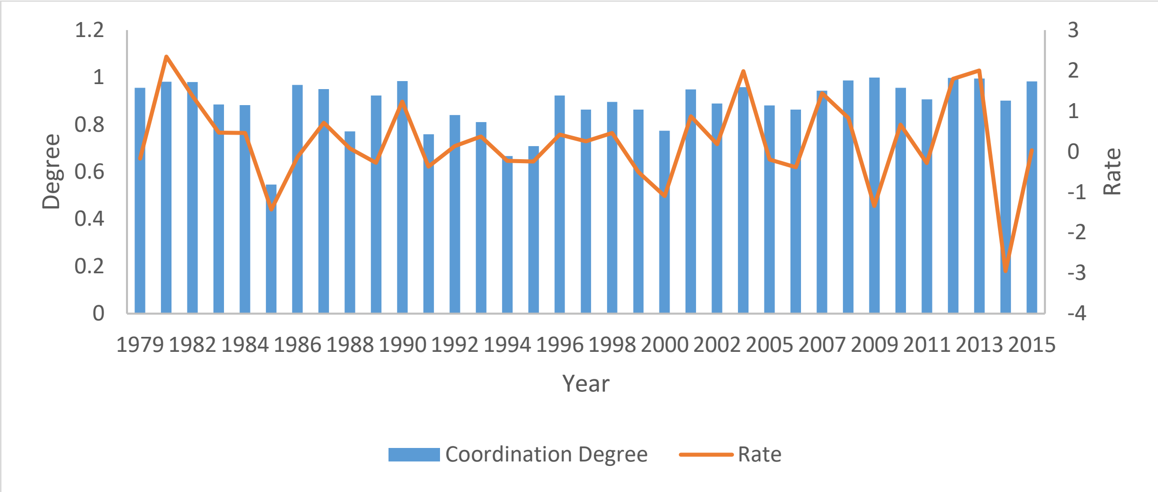

Figure 5: Coupling coordination degree and rates between geothermal adoption and the economy in Beijing

5. CONCLUSIONS

This paper investigates the relationships among geothermal water, water consumption, centralized heat supply and energy consumption with geothermal adoption using the water-heat-energy nexus for the time span from 2001 to 2015 using a vector autoregression model, an impulse response function and variance decomposition methods. Based on the water-heat-energy nexus, we adopt a gear model and a coupling coordination model to illustrate the coupling coordination degrees between geothermal adoption and the economy in Beijing. It is demonstrated that geothermal adoption changes as the varying contribution gradually decreases. Geothermal adoption is mainly affected by its own historical development in the first two years, and then, it is mainly affected by water consumption. Water consumption mainly affects geothermal adoption. Water consumption and energy consumption have negative effects on geothermal adoption, while the centralized heat supply has a positive effect on geothermal adoption. The centralized heat supply has the smallest impact on geothermal adoption, while this influence is increasing, and energy consumption has a greater impact on geothermal adoption. The rates of geothermal adoption and the regional economy vary, but they are in a good state of coupling coordination, which is more than 0.5.

This study effectively complements existing research and provides important suggestions for regional policy makers.

(1) Promoting geothermal adoption is a complex system involving water consumption, energy supply and demand, and the heating system. Each effect on geothermal adoption should be assessed. Even though China's recent policies actions have broken the high-cost limitations and have stimulated investment in geothermal adoption, the utilization of geothermal water (Jiang et al., 2016), which is related to water consumption, heating and energy use, is undoubtedly facing enormous development problems.

(2) Governments should pay more attention to the water-heat-energy system when they begin to utilize geothermal sources. They should plan for geothermal adoption, which may affect the regional economy and environment.

(3) Governments should formulate regulations that are related to geothermal adoption. Geothermal enterprises should focus on the geothermal water recirculation and how geothermal water affects heating and energy consumption.

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