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Long-Term and Short-Term Effects of Carbon Emissions on Regional Healthy Development in Shanxi Province, China

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Abstract: As an important energy base in China, the economic development of Shanxi Province highly depended on coal resources. However, huge coal consumption produced a large amount of carbon dioxide and aggravated ecological problems. Thus, this study uses energy consumption, GDP, and the urbanization rate from 1981 to 2020 via the Vector Auto Regressive (VAR) and impulse response function to analyze the interaction among carbon emissions, urbanization, and economic growth in Shanxi Province. The results show that relations among carbon emissions, economic growth, and urbanization are complicated, and all three have a long-term stable equilibrium relationship. The lag effect on each other reacts violently in the short term, and gradually becomes gentle over time. In the short term, carbon emissions are positively correlated with economic growth and have the same trend of change, but in the long run, carbon emissions will have a small hindering effect on economic growth. Carbon emissions reduce urbanization levels in the short term, and then gradually climb, tending to stabilize as time goes by. With respect to receiving economic growth impaction, carbon emission increases at the initial stage of economic development, but the growth rate becomes slow as time goes by. With respect to receiving urbanization impaction, carbon emission first declines and then rises slowly with relatively small and slow growth in general. The relations among carbon emissions, economic growth, and urbanization are complicated. Therefore, local government needs to be very cautious in regional governance, especially in economic and urban planning and design, take various factors into consideration, and adhere to low-carbon, green, and circular development so as to achieve the carbon peak and carbon neutrality as scheduled and make the urban economy develop sustainably.

Keywords: carbon emissions; economy growth; urbanization; regional governance; Shanxi province

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1. Introduction

The Paris Agreement reached in 2015 set out the goal of working to limit temperature rise to 1.5 °C [1]. According to the 1.5 °C special report released by IPCC, achieving the 1.5 °C target requires the world to achieve net zero emissions around 2050 [2]. In September 2020, China put forward a new goal to achieve carbon neutrality by 2060 [3]. The Fifth Plenary Session of the 19th CPC Central Committee, which opened on 26 October 2020 in Beijing, reviewed and adopted proposals for the 14th Five-Year Plan (2021–2025) for Economic and Social Development and targets, for 2035, a top-level policy blueprint for China's mid-and long-term development [4]. The meeting made it clear that China's economy has already come to the stage of high-quality development, and it is in a critical period of changing the mode of development, optimizing the economic structure, and changing the power of growth. There is no doubt that regional governance plays an increasingly important role in local sustainable development [5,6]. Since rapid development of human society accelerates global urbanization, the world population has increased sharply from 1 billion in 1900 to 7.6 billion at present, which has caused environmental pollution, carbon emissions, climate warming, and other increasingly serious global problems [7–10], and the relationship between carbon emissions and economic growth and urbanization has been the subject of increasing attention from scholars at home and abroad [11–15].

Low-carbon development is based on the theory of sustainable development, extending its connotation from ecological environment governance to the green economy and low-carbon economy [16]. In 2003, the British government published the Energy White Paper "Our Energy Future: Building a Low-carbon Economy", which, for the first time, proposed the development of a low-carbon economy and accelerated the global low-carbon development transition process [17]. In 2015, climate change action was included as one of the major goals in the UN 2030 Agenda for Sustainable Development, and countries around the world called for action to achieve the Sustainable Development Goals [18]. Carbon emission research has become a significant issue facing the global trend to actively respond to climate; government from countries, regions, cities, and rural areas began to explore low-carbon development models [19]. Currently, most research on the 1.5 target path is focused on the global level [2,20,21]. Based on further reducing energy demand and adjusting energy structure to reduce emissions [21,22], Rogelj et al. [20] discussed possible paths to achieve climate change targets at the global level and pointed out that in addition to energy structure adjustment, the application of negative emission technologies should be increased. Alam et al. [23] analyzed Brazil, India, Indonesia, and China's carbon emissions, and found that carbon dioxide emissions would decrease with the increase of China's income level, while carbon dioxide emissions in India would not decrease with the increase of income. Wang et al. analyzed the relationship between urban development and energy carbon emissions in China and found that the development of secondary industry and tertiary industry has a great driving effect on total energy consumption and energy carbon emissions [24]. Some scholars have carried out studies on China's transition path under the constraints of climate targets for carbon emissions, including discussions on individual sectors such as construction [25] and electricity [26].

Given that carbon emission is a problem that may have a profound impact on sustainable development and energy use is a big contributor to carbon emissions, a number of studies have examined possible relationships between energy use and urbanization at home and abroad [14,15]. Wang et al. found that the average annual carbon emissions of urban energy consumption accounted for 80% of the average annual total carbon emissions in their multi-year accounting study of Wuxi City [27]. Bilgili et al. analyzed the statistical data of 10 Asian countries from 1990 to 2014 and found that urbanization has an important long-term impact on energy density [28]. Wang et al. conducted a study on energy consumption and carbon emission of urbanization economic growth in 170 countries in 1980 and 2011 and found that each variable had Granger causality to varying degrees [29]. Asumadu-Sarkodie and Dwusu used electricity consumption to characterize urban development and found that electricity consumption and carbon emissions were dynamically correlated, with inconsistent coupling characteristics in different stages [30].

With the development of information technology, many mathematical methods are used in the study of carbon emissions. Grossman et al. (1991) proposed the environmental Kuznets curve (EKC) and believed that the relationship between environmental pollution and economic growth was in the shape of an inverted U [11]. Subsequently, Selden (1994) and Martinez (2004) confirmed the existence of this curve through their studies [12,13]. Zhang and Lin established the Kopp Douglas model by using China's provincial panel data and found that urbanization promoted the rise of energy consumption, but its impact effects were significantly different in the eastern, central, and western regions [31]. Adebayo et al. used auto regressive distributed lag (ARDL) and wavelet coherence approaches to reveal the determinants of environmental degradation in Thailand [32]. Odugbesan and Aghazadeh determined environmental pollution and economic policy uncertainty in Japan by empirical study [33]. Adebayo et al. explained the sustainability of the energy-induced growth nexus in Brazil and its impact on carbon emissions and urbanization [34]. Various studies have utilized different models to investigate the key factors of carbon emissions [35,36]; for example, some scholars take the Logarithmic Mean

Division Index (LMDI) factor decomposition method to analyze the impact of economic growth on carbon emissions [37–39]. Adebayo and Odugbesan find empirical evidence to model carbon dioxide emissions in South Africa using the ARDL-based bounds and wavelet coherence techniques [40]. In terms of carbon emissions factors, the Stochastic Impacts by Regression on Population, Affluence, and Technology model (STIRPAT) is the main method to study the impact of urbanization on carbon emissions [41–43]. In addition, the three-stage least square method [44], the co-integration and error correction model [45] and the panel threshold model [46] have been used in corresponding studies. Scholars adopted the principles of econometrics and selected key variables to conduct a quantitative analysis and prediction of the relationship between carbon emissions and influencing factors at a macro level [47]. York et al. compared analytic tools and found that more accurate analysis results can be obtained by STIRPAT [48]. The linear panel method is used to study and confirm the long-term equilibrium relationship between energy transition and carbon emissions [49].

Although these methods greatly reduce the complexity of the model and the amount of calculation by screening the key influencing variables, the interrelationship between variables cannot be considered, and model interpretability is poor. Therefore, although existing methods have concluded that population and the economy have a greater impact on total carbon emissions and energy intensity has a greater impact than energy structure [50], they cannot explain the interaction between internal variables. However, in the actual system development process, there are interaction relations among variables (including time lag and effect degree). VAR and impulse response can explain the cause of an impact on a variable at different times and reflect the dynamic influence path of one variable on another. The VAR (Vector Auto Regressive) and VEC (Vector Error Correction) models are used to study the relationship between carbon emissions and economic growth [51–55], although some studies use decoupling theory to find this relationship [56,57]. However, there are relatively few studies on the interaction among carbon emissions, economic growth, and urbanization in the Yellow River Basin.

The Yellow River Basin, regarded as the "energy basin", is rich in coal, natural gas, oil, and non-ferrous metals. Its coal reserves accounted for more than half of China's total coal reserves [58]. As an important chemical, raw materials, and energy industrial base in China, Shanxi, located in the Yellow River Basin, contains 1053 coal mines with a planning capacity of around 1.2 billion tons spread across the whole province [59], and plays a vital role in the national economic development and the construction of an all-round well-off society [60]. With the coal industry serving as a pillar industry in this region, about 70% of the coal is sold to other provinces, and more than 65% of the remainder is used by heavy industry (i.e., petroleum processing, coking and nuclear fuel processing, production and supply of electricity and heat, etc.). Usually, Shanxi is named as a "Black GDP" province to reflect its coal-driven economic structure, but according to the statistics from Shanxi Coking Coal Group, the collapsed area of mined-out regions has reached 11.2 hm^2, in which the damaged housing area per capita has reached 4.5 m^2 [61].

In fact, Shanxi is also one of the cradles of Chinese civilization; Mount Wutai, Pingyao County, and the Yungang Grottoes are all included in the world cultural heritage list [62]. In recent years, social and economic indicators in Shanxi Province have developed rapidly with favorable geographical conditions, demographic dividends, and policy support. Shanxi Province's economic development is of great significance to narrow the gap between the rich and the poor and to achieve the national goal of building a well-off society. Unfortunately, its economic growth mode is highly dependent on resources, consumes a large amount of non-renewable energy, produces a large amount of carbon dioxide, and aggravates the problem of environmental pollution. Facing the ecological crisis, China's State Council has chosen Shanxi as a reform demonstration project pilot region. The transformation calls for an understanding of the relationship between carbon emissions and economy growth in the context of urbanization. Therefore, on the basis of previous studies, this paper conducted an empirical study of the dynamic relationship between carbon emissions, economic level, and urbanization in Shanxi Province from 1981 to 2020 by constructing a VAR model, and analyzed the interaction mechanisms among the three.

The paper consists of five sections. The introduction section explains the objective, motivation, novelties, and structure of the paper. The objective of this study is to find the interaction mechanisms among the carbon emissions, economic level, and urbanization in Shanxi, and put forward a suggestion for Shanxi Province and similar regions to formulate reasonable low-carbon and sustainable development plans. Although some studies use quantitative analysis to uncover this relationship, there are relatively few studies on the interaction among carbon emissions, economic growth, and urbanization in coal-based region. As an important energy industrial base in China, Shanxi contains 1053 coal mines with a planning capacity of around 1.2 billion tons spread across the whole province; the economy highly relies on coal which also causes collapsed areas of mined-out regions and air pollution. The unique aspect of the research is that we chose Shanxi as such a typical coal-based region to study the carbon emissions. The motivation of the research is to face the ecological crisis, and to better understand the relations between carbon emissions and economy growth in the context of urbanization. The next section explains the method, research area, and data resource in detail. The findings and analysis process are presented in Section 3. The discussions section improves in reference to previous studies that are incongruent to or contrast with the study findings. The final section contains the main conclusions, and the limitations of this study and potential for further research.

2. Method and Study Area

2.1. Method

In 1980, American economist Christopher Sims created VAR, which has become the working principle of how each endogenous variable change in future trends can be predicted by the corresponding endogenous variable values in the past, with the flexibility of the single variable regression model being that it can under certain conditions be associated with a multivariate vector auto-regressive model [63]. Subsequently, Engel and Granger (1987) put forward the concept of cointegration and VECM to analyze and identify the long-term equilibrium relationship between non-stationary variables [64]. Johansen (1995) and Hendry (1995) developed VECM by applying a cointegration concept to VAR model [65,66]. VAR models have been used empirically in many investigations to examine short-run and long-run relationships. For example, Mohamed Mabrouki (2017) used VAR models to study the relationship between economic growth and development in Tunisian from 1970 to 2015 [67]. Erdenebat Bataa et al. (2019) used VAR models to study changes in the relationship between short-term interest rate, inflation, and growth: evidence from the UK, 1820–2014 [68]. Kamaljit Singh and Simmi Vashishtha (2020) used VAR to study the long-term equilibrium relationship between per capita energy consumption and per capita GDP in India from 1970 to 2015 [69]. By using a VAR model, Friday Osemenshan Anetor (2019) examined the effect of FDI on the real sector in Nigeria between the periods 1981–2016 via VAR [70]. Using quarterly data spanning 1960–2017, Mahua Barari and Srikanta Kundu (2019) estimated a VAR model involving federal funds rate, real GDP growth, and a housing variable and conducted a time series analysis for the pre- and post-crisis periods [71]. Therefore, this paper uses the VAR model to examine the short-run and long-run relationships among carbon emissions, economy growth, and urbanization. The VAR model containing p endogenous variables with reduced form is expressed as follows:

$$X_t = \prod_1 X_{t-1} + \prod_2 X_{t-2} + \ldots + \prod_k X_{t-k} + \Phi D_t + \varepsilon_t, \quad t = 1, \ldots, T,\ \varepsilon_t \sim IN(0, \Omega) \quad (1)$$

Here, X_t is $p \times 1$ vector, k is lag order, Π_i is coefficient of $p \times p$ matrix, D_t includes intercept term, trend term, dumb variables, etc. The mean value of error term ε_t is zero. Covariance matrix Ω is a positive definite matrix, that is, it is assumed that ε_t does not exit sequence autocorrelation but co-correlation. The VAR model describes the statistical nature of data, that is, the co-correlation between variables [65].

2.2. Study Area

Shanxi Province, located in the North China Platform, covers 11 cities, 85 counties, and 11 county-level cities, see Figure 1. The topography of Shanxi is complex and consists of various geomorphological types, such as mountains, hills, plateaus, basins, and platforms [59]. In recent years, social and economic indicators in Shanxi Province have developed rapidly with favorable geographical conditions, demographic dividends, and policy support. From 1981 to 2020, the GDP of Shanxi increased from 19.25 billion $ to 279.25 billion $ meanwhile, urbanization rate increased from 20.6% to 62.5%. However, due to the over-reliance on resources for economic growth, Shanxi Province consumes a large amount of non-renewable energy and generates a large amount of carbon dioxide to produce its rapid economic development, which aggravates environmental pollution.

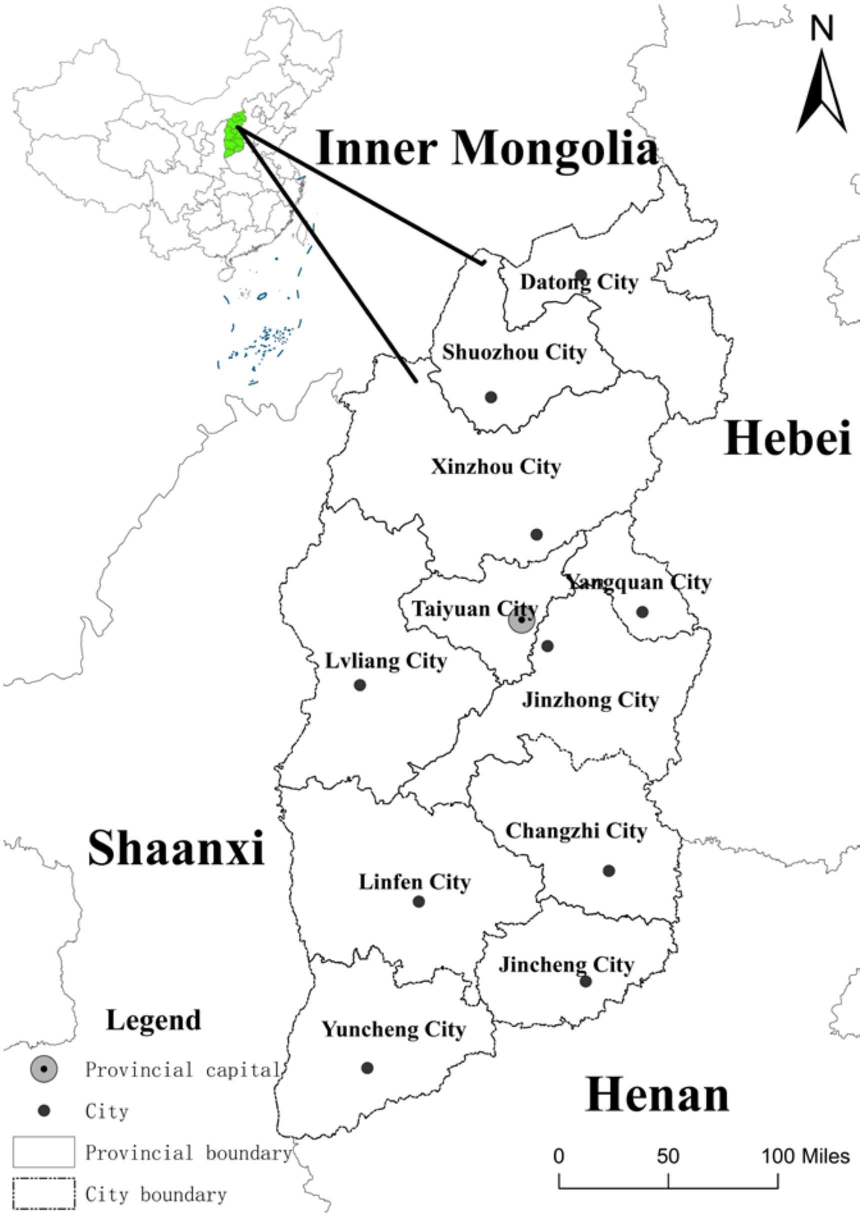

Figure 1. The map of Shanxi province.

2.3. Date Resources

In terms of the energy consumption structure of Shanxi Province, the consumption of raw coal, coke, oil, electricity, and natural gas is the main body, as well as the main source of carbon emissions. Hence, we use these items' consumption to estimate the carbon emissions of Shanxi Province. The calculation formula is:

$$CE = \sum_{i=1}^{5} (CE)_i = \sum_{i=1}^{5} E_i \theta_i \delta_i \tag{2}$$

where CE represents the total carbon emission of energy consumption, $(CE)_i$ represents the carbon emission of the ith energy, and E_i represents the consumption of the ith energy. θ_i represents the standard coal coefficient of the ith energy, and δ_i represents the carbon emission coefficient of the ith energy.

The energy consumption, GDP, and urbanization rate were drawn from the Shanxi Statistical Yearbook (1982–2021) through function (2), and the standard coal coefficient and carbon emission coefficient were drawn from the provincial Greenhouse Gas Inventory Compilation Guide (No. 1041(2011) of the Climate Office of National Development and Reform). The carbon emissions and a summary of the descriptive statistics are shown in Table 1.

Table 1. Summary of descriptive statistics.

Variable	N	Minimum	Maximum	Mean	Standard Deviation	Variation
UR	40	0.21	0.63	0.38	0.13	0.02
EG	40	121.70	17,651.90	4952.04	5577.25	31,105,760.68
CE	40	3047.81	26,524.34	13,136.11	7891.11	62,269,634.69

3. Results and Analysis

3.1. Stationarity Test

When the time series data are stable, further steps such as VAR model construction and the impulse response function can proceed smoothly. When the data are not stable, the probability of false regression is very high, and the conclusion is not reliable. We used the Augmented Dickey–Fuller, Phillips–Perron, and Dickey–Fuller GLS (ERS) method to perform a unit root test, and the test results are shown in Table 2.

Table 2. Unit root test.

Variable	Test Type	t Statistic	Significance Level Critical Value			p	Verdict
			1%	5%	10%		
CE	Augmented Dickey–Fuller	−2.030489	−4.219126	−3.533083	−3.198312	0.5664	unstable
	Phillips–Perron	−1.678684	−4.211868	−3.529758	−3.196411	0.7417	unstable
	Dickey–Fuller GLS (ERS)	−2.175237	−3.77	−3.19	−2.890000	0.0363	stable
ΔCE	Augmented Dickey–Fuller	−4.872899	−4.219126	−3.533083	−3.198312	0.0018	stable
	Phillips–Perron	−4.729038	−4.219126	−3.533083	−3.198312	0.0027	stable
	Dickey–Fuller GLS (ERS)	−5.010148	−3.77	−3.19	−2.890000	0	stable
EG	Augmented Dickey–Fuller	−0.152411	−4.211868	−3.529758	−3.196411	0.992	unstable
	Phillips–Perron	−0.390432	−4.211868	−3.529758	−3.196411	0.9845	unstable
	Dickey–Fuller GLS (ERS)	−1.200646	−3.77	−3.19	−2.89	0.2377	unstable
ΔEG	Augmented Dickey–Fuller	−4.886404	−4.219126	−3.533083	−3.198312	0.0017	stable
	Phillips–Perron	−4.891815	−4.219126	−3.533083	−3.198312	0.0017	stable
	Dickey–Fuller GLS (ERS)	−4.988007	−3.77	−3.19	−2.89	0	stable
UR	Augmented Dickey–Fuller	−0.547331	−4.219126	−3.533083	−3.198312	0.9766	unstable
	Phillips–Perron	−0.842275	−4.211868	−3.529758	−3.196411	0.9525	unstable
	Dickey–Fuller GLS (ERS)	−1.57701	−3.77	−3.19	−2.89	0.1246	unstable
ΔUR	Augmented Dickey–Fuller	−8.611742	−4.219126	−3.533083	−3.198312	0	stable
	Phillips–Perron	−8.228623	−4.219126	−3.533083	−3.198312	0	stable
	Dickey–Fuller GLS (ERS)	−8.755748	−3.77	−3.19	−2.890000	0	stable

Note: ΔCE, ΔEG, and ΔUR represent the first order difference of the variables CE, EG, and UR, respectively.

3.2. The Determination of the Optimal Lag Order

The optimal lag order of the VAR model can be accurately determined by a lag order test and an AR characteristic unit circle test. Researchers generally determine the order according to the minimum criteria of Akaike information criterion (AIC), Schwarz information criterion (SC), final prediction error (FPE), Hannan–Quinn information criterion (HQ), and other indicators. If the result cannot be obtained, the maximum sequential modified LR test statistic (LR) value is used to judge. Based on the results of AIC, LR, FPE, SC, and HQ, when the lag order is 2, multiple tests are more significant. It also expresses the optimal lag order. Furthermore, the characteristic values are all within the AR unit circle, no root lies outside the unit circle, so VAR satisfies the stability condition.

3.3. Co-Integration Test

The co-integration test is a test method used to judge whether there is a long-term equilibrium and stable relationship between variables. Compared with other methods, the Johanson co-integration test has the advantages of simple operation and high accuracy and is often used in the case of a large number of variables [51,52]. Therefore, this paper adopted the Johanson co-integration test to test the relationship between variables, and the test results are shown in Table 3.

Table 3. Johanson co-integration test.

Original Hypothesis	Eigenvalue	Trace Test	0.05 Critical Value	*p*	Max-Eigen Test	0.05 Critical Value	*p*
Hypothesis 1: *None **	0.393625	30.40582	29.79707	0.0425	18.50951	21.13162	0.1119
Hypothesis 2: *At most 1*	0.268691	11.89632	15.49471	0.162	11.57799	14.2646	0.1275
Hypothesis 3: *At most 2*	0.008566	0.318324	3.841466	0.5726	0.318324	3.841466	0.5726

Note: * denotes rejection of the hypothesis at the 0.05 level.

As can be seen from Table 3, the *p* values of trace test and max-eigen test for hypotheses 2 and 3 were both greater than 0.05, which does not reject the null hypothesis. The *p* value of max-eigen test for hypothesis 1 was also bigger than 0.05, so that the null hypothesis cannot be rejected. The *p* value of trace test for hypothesis 1 was less than 0.05, rejecting the null hypothesis that there is no single co-integration relationship, indicating that there is at least one co-integration relationship between the variables; that is, there is a long-term stable equilibrium relationship between variables.

3.4. The VAR Model of CE, EG, and UR

Once the optimal lag order was determined, a VAR model was constructed via Formula (3), shown as follows:

$$CE = 0.7622CE_{t-1} - 0.4616CE_{t-2} + 0.4543EG_{t-1} - 0.0997EG_{t-2} - 1.6026UR_{t-1} + 0.9034(UR)_{t-2} + \mu_t + 4.0940 \quad \mathrm{R}^2 = 0.9901,\ \mathrm{AdjR}^2 = 0.9882 \tag{3}$$

$$EG = 0.2335CE_{t-1} - 0.2906CE_{t-2} + 1.0692EG_{t-1} - 0.0364EG_{t-2} - 0.9955UR_{t-1} + 0.7201(UR)_{t-2} + \mu_t + 0.5003 \quad \mathrm{R}^2 = 0.9977,\ \mathrm{AdjR}^2 = 0.9972 \tag{4}$$

$$UR = -0.0100CE_{t-1} + 0.0035CE_{t-2} - 0.0375EG_{t-1} + 0.0448EG_{t-2} + 0.6956UR_{t-1} + 0.2683(UR)_{t-2} + \mu_t + 0.0384 \quad \mathrm{R}^2 = 0.9966,\ \mathrm{AdjR}^2 = 0.9959 \tag{5}$$

It can be seen from Equations (3)–(5) that the status of the three variables, carbon emissions, economic growth, and urbanization level, will have an impact on the variables themselves and other variables, that the impact is not immediate, and that there is a lag effect in the short term. It is worth noting that the lag phase I and lag phase II influence of all factors is opposite, which implies that the relationship between each factor and itself and other factors fluctuates in the short term.

The Roots of Characteristic Polynomial was 0.993455 − 0.027116i, 0.993455 + 0.027116i, 0.436063 − 0.443912i, 0.436063 + 0.443912i, −0.329985, −0.002101, respectively. Correspondingly, the modulus was 0.993825, 0.993825, 0.622261, 0.622261, 0.329985, 0.002101, respectively. Obviously, no root lies outside the unit circle (see Figure 2). Therefore, the VAR model satisfies the stability condition.

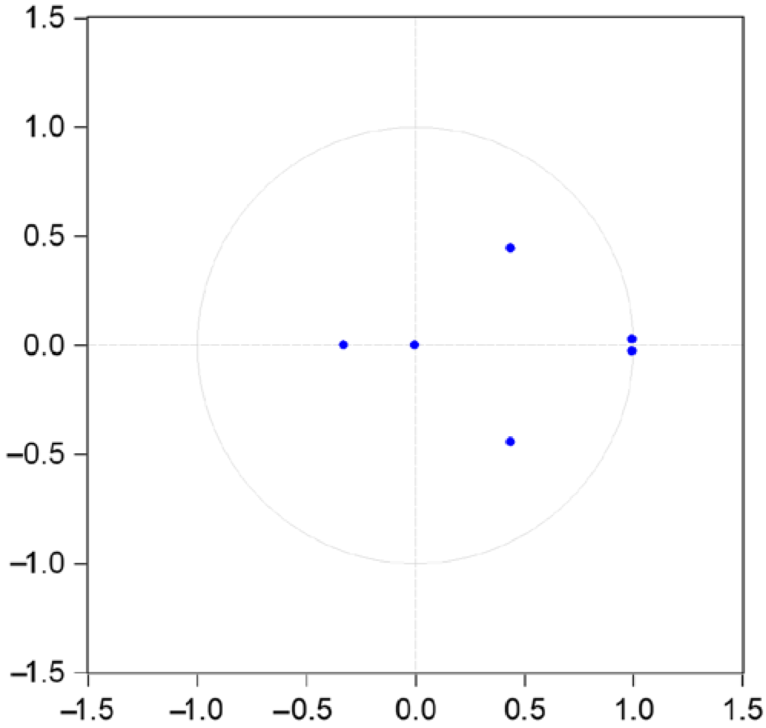

Figure 2. Inverse Roots of AR Characteristic Polynomial.

Equation (3) shows that, in terms of carbon emissions, the elasticity coefficient of carbon emissions and economic growth is negative in lag phase II but positive in lag phase I, which reveals that they have an increasing positive impact on carbon emissions, and that influence from carbon emissions themselves is most significant among them. Because coal, petroleum, and other fossil energy dominate energy consumption in Shanxi, new clean energy is still low. The economic growth mode of Shanxi Province is still not completely out of resource dependence in the short term, and it is bound to increase the emissions of carbon dioxide. In contrast, the elasticity coefficient of urbanization level is positive in lag phase II but negative in lag phase I. The goodness of fit of the model Equation (3) is presented by the R^2 (0.9901) and AdjR^2 (0.9882) accordingly.

As seen from Equation (4), in terms of economic growth, the elasticity coefficient of carbon emissions and economic growth is negative in lag phase II but positive in lag phase I. In contrast, the elasticity coefficient of urbanization level is positive in lag phase II but negative in lag phase I. In the early stage of urbanization, rapid urbanization has brought a large labor force, including many high-tech workers, which has enhanced the radiation and diffusion effect of urban centers to effectively boost economic growth; however, if the population size reaches the threshold, even exceeds the urban carrying capacity, it will have a negative impact on the economy. The goodness of fit of the model Equation (4) is presented by the R^2 (0.9977) and AdjR^2 (0.9972) accordingly.

According to Equation (5), in terms of urbanization level, the elasticity coefficients of carbon emissions, economic growth, and urbanization level were also positive in lag phase II but negative in lag phase I. However, it is important to note that the effect of the two decrease over time, probably because with the proposal of dual carbon targets and the implementation of energy conservation and emission reduction policies, cities must reasonably control population size. The goodness of fit of the model Equation (5) is presented by the R^2 (0.9966) and AdjR^2 (0.9959) accordingly.

Granger causality test is created by Clive W.J. Granger to analyze the Granger causality between economic variables. From Table 4, the original hypothesis that EG is not the Granger cause of CE, the probability of rejecting it to make the first type of error is 0.002, which indicates that at least at 99.5% confidence level, EG can be considered as the Granger cause of CE. Moreover, EG can be considered as the Granger cause of UR at least at 99.5% confidence level.

Table 4. VAR Granger causality tests.

Dependent Variable	Excluded	Chi-Sq	df	Prob.	Null Hypothesis
CE	EG	12.40813	2	0.002	
	UR	3.513237	2	0.1726	
	All	13.27646	4	0.01	
EG	CE	1.967703	2	0.3739	
	UR	0.654709	2	0.7208	
	All	2.456159	4	0.6525	
UR	CE	0.226869	2	0.8928	
	EG	4.953261	2	0.084	
	All	8.409556	4	0.0777	

3.5. Mutual Influence and Trend

The VAR model can only reflect the causal relationship between variables within a short time range, while the impulse response function diagram can intuitively express the interaction and changing trends between variables, as shown in Figure 2.

It can be seen from Figure 3 that for carbon emissions, being impacted by themselves, the impulse response rose slowly at first, then showed a downward trend. However, the downward speed was fast first, then slow, and then gradually became stable when it fell back to a certain height, reflecting the lag effect of carbon emissions on itself in that this metric gradually decreases and tends to converge as time goes by. With respect to receiving economic growth impaction, impulse responses of carbon emissions showed an increasing trend in the first two periods, and then began to fall and gradually stabilized, indicating that carbon emissions increased at the initial stage of economic development, but the growth rate slowed down as time went by. With respect to receiving urbanization impaction, the impulse response of carbon emissions first declined and then rose after reaching the lowest value in the second stage, with relatively small and slow growth in general.

As seen from Figure 3, in terms of economic growth, when impacted by carbon emissions, the impulse response rose in the first three periods, then tends to be flat and at last falls back slightly. Similarly, being impacted by itself, the impulse response of economic growth also rose slowly at first then tended to be flat and at last fell back slightly. The similar trends indicate that carbon emissions and economic growth have the same positive change trend in the short term, but in the long run, carbon emissions will have a small hindering effect on economic growth. With respect to receiving urbanization impaction, the impulse response of economic growth first declined and then tended to a wavelike rising trend, with relatively small and slow growth in general.

As far as urbanization was concerned, after receiving the impaction of carbon emissions, the impulse response of urbanization decreased slowly in the first two periods, then stayed in a relatively stable situation, which revealed that the long-term effects of carbon emissions on urbanization are not obvious. With respect to receiving economic growth impaction, impulse responses of urbanization showed a slight downward trend in the short term and tended to be stable after reaching a certain level. It is worth noting that the urbanization level had a sharp response to the impact from itself and presented an overall downward trend, with a decreasing speed from fast to slow.

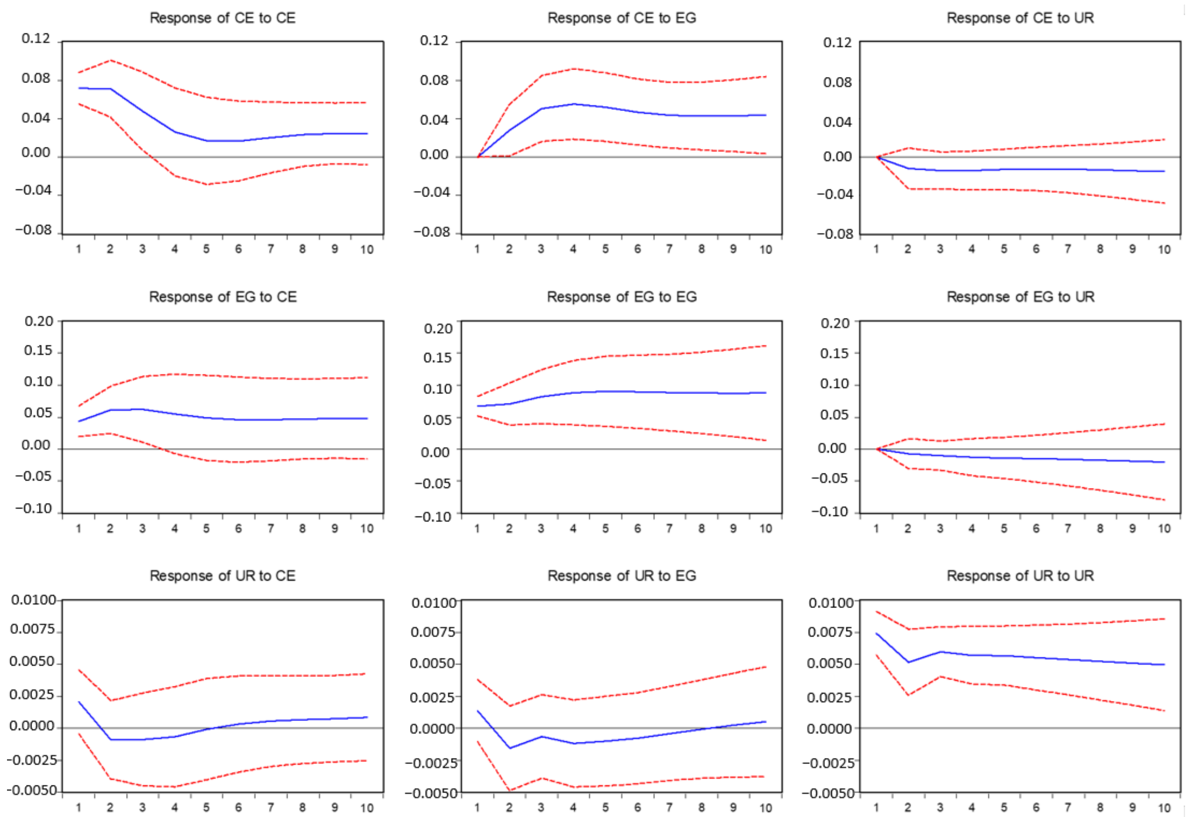

Figure 3. The impulse response of carbon emissions, economic growth, and urbanization.

4. Discussion

For a long time, Shanxi's economic development mainly depended on the consumption of non-renewable energy, which not only aggravated the exhaustion of resources and caused great pressure on the ecological environment, but also produced a large number of harmful gases to pollute the air [72]. President Xi Jinping's speech at the "Symposium on Ecological protection and High-quality Development in the Yellow River Basin" clearly pointed out that the Yellow River Basin is of great significance to China's economic and social development and ecological security. However, due to the limited energy consumption structure still being dominated by coal and low utilization efficiency, the task of carbon dioxide reduction in Shanxi is arduous [60].

Based on the impulse response function, we found that there is a long-term stable equilibrium relationship between carbon emissions, economic growth, and urbanization, and all three have a lag effect in the development process, implying that relations among carbon emissions, economic growth, and urbanization are complicated. In the early stage of urbanization, population concentration and energy consumption led to an increase in carbon emissions, which is in line with research of Cole and Neumayer which found that there is a positive correlation between population urbanization and carbon dioxide emissions [73]. This conclusion is also consistent with Chinese scholars' Wang and Su's findings, that urbanization level is the main driving force of a significant increase in carbon emissions [74]. However, the urbanization level became negative to carbon emissions with the passage of time, possibly because Shanxi is the national resource-based economic transformation comprehensive supporting reform pilot zone approved by The State Council on 25 November 2010, local governments will pay more attention to low-carbon, green and energy-saving development. It is important to note that the effect of this development is not immediately visible but showing up over time. Moreover, we found that in the early stage of urbanization, the influence of carbon emission and economic growth on urbanization gradually increased; to some extent, carbon emissions are closely related to industrialization, which inevitably requires a large labor force, thus promoting the migration of a large number of peasants to cities and thus accelerating the urbanization process, which is in line with the research of Hu and Wang [45]. In addition, carbon emission has a positive impact on economic growth, which is in line with research of Li et al. which found that carbon emissions would boost GDP per capita in the short term [75]. Probably because Shanxi is a typical resource-based region in China, its coal output accounts for about 25% of the country output, making the coal industry a pillar industry. Economic growth is positively correlated with the increase of carbon emissions caused by energy consumption.

Therefore, in order to promote sustainable development in Shanxi Province, local governments need to be very cautious in economic and urban planning and design. For instance, with the deepening of supply-side structural reform, Shanxi, which mainly relies on the traditional resource economy, is also seeking new economic development modes, and its economic growth rate has slowed down, which will also slow the speed of urbanization development. Since Shanxi is rich in solar energy, wind energy, and other resources, the government should strengthen their development and utilization, adjust the energy consumption structure, and increase investment in R&D. Tourism is an industry with low energy consumption and low pollution, and it is also an important industry to cope with climate change, promote energy conservation and emission reduction, and develop a low-carbon economy [76]. Since Shanxi has the characteristic Taihang mountains and the Yellow River basin as its natural landscape, in addition to an abundant humanities landscape, including the Yungang grottoes and the Pingyao Ancient City [62], there are advantages to speeding up the development of tourism resources, promoting the transformation and upgrade of industrial structures, and speeding up the transformation of economic development patterns.

5. Conclusions

As an important energy base in China, the economic growth mode of Shanxi Province is highly dependent on resources, consumes a large amount of non-renewable energy, produces a large amount of carbon dioxide, and aggravates the problem of environmental pollution. Resource-based cities must urgently analyze the dynamic relationship and interaction mechanisms among carbon emissions, economic level, and urbanization to lead high-quality development in the region. In this paper, the VAR model and the impulse response function were used to study the interaction between energy consumption, carbon emissions, economic growth, and urbanization levels in Shanxi Province. The results show that relations among carbon emissions, economic growth, and urbanization are complicated, and all three have a long-term stable equilibrium relationship. The lag effect on each other reacts violently in the short term, and gradually tends stabilize as time goes by. In the short term, carbon emissions are positively correlated with economic growth and have the same trend of change, but in the long run, carbon emissions will have a small hindering effect on economic growth. Carbon emissions reduce urbanization levels in the short term, and then gradually climb, at last tend to stabilize as time goes by. With respect to receiving economic growth impaction, carbon emissions increased at the initial stage of economic development, but the growth rate slowed down as time went by. With respect to receiving urbanization impaction, carbon emissions first declined and then rose with relatively small and slow growth in general. Therefore, the local government needs to be very cautious in economic and urban planning and design, take various factors into consideration, and adhere to low-carbon, green, and circular development so as to achieve the carbon peak and carbon neutrality as scheduled for the healthy development of the urban economy.

This article still has some shortcomings. For example, the space span of the article was macroscopic and in future analyses can be refined from the provincial level to the city and county levels. Finally, the selection of factors was based on the availability of data, and the selection range was narrow; therefore, the selection of these indicators needs to be studied further.

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