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Construction of a Comprehensive Energy Price Index for Prefecture-level Cities: The Case of Shanxi Province

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Abstract: *Cities are the major consumers of energy in China. China's energy consumption structure has long been characterised by a high share of coal, and nowadays the consumption and external dependence of oil and natural gas are also increasing.The current state of energy consumption generates two major problems. The first is the inadequacy of the conventional method of using only crude oil prices as a proxy variable for energy prices. Secondly, the reference of provincial composite energy price indexes to prefecture-level municipalities is also deficient. Based on these two issues, this study proposes a methodology based on the downscaling method and Divisia's composite energy price index to calculate the composite energy price index for prefecture-level cities.Applying the methodology presents a composite energy price index for eleven prefecture-level cities in Shanxi Province.This study presents a reference for the future construction of a comprehensive energy price index for each prefecture-level city in China.*

Keywords: *Statistical downscaling method; Spearman correlation analysis; Divisia Composite Energy Price Index*

1. Introduction

Due to the outbreak of the fourth Middle East war in the early 1970s, which led to global oil shortages and skyrocketing oil prices, resulting in a severe global economic crisis, the issue of energy prices has gradually been taken seriously by academics, and the connotation is expanding to cover a wide range of aspects, such as national energy price indices and provincial energy price indices.

With rapid economic development, China is now one of the world's largest energy consumers and carbon dioxide emitters.[1]Cities are now the main consumers of energy in China.China is now the world's largest primary energy consumer. [2]According to the United States Energy Information Administration (EIA) and BP (2011), 85 per cent of China's carbon dioxide emissions come from urban energy consumption, much higher than 80 per cent in the United States or 69 per cent in Europe.[3]

As a consequence, it is important to fill in the empty space of comprehensive energy price indicators for prefecture-level cities in China.

There are challenges in constructing indicators for prefecture-level municipalities. Data on energy consumption and industrial products are incomparable and very limited at the prefecture level for most of China.[4]To solve this problem, this paper uses the downscaling method to extrapolate the energy consumption of prefecture-level cities from the provincial energy consumption.

This paper uses the prices of the three main primary fossil energy sources, coal, oil and natural gas, to construct a new Divisia energy price index that comprehensively measures the consumption and prices of the three energy sources at the prefecture level, applies data from Shanxi Province to project the Divisia Composite Energy Price Index for eleven prefecture-level cities.

2. Methodology

2.1 Divisia Composite Energy Price Index

The Divisia index was first proposed by Divisia (1925) in a study on monetary indices and monetary theory.[5]

In this study, we use the Divisia index construction method by Kang Jijun.[6]

The results of the index construction are as follows:

$$E_t = 100e^{\lambda_t} \quad \text{(Divisia Composite Energy Price Index)} \tag{1}$$

$$\lambda_t = \sum_{t=1}^{T}\left[\sum_{i=1}^{3}\frac{1}{2}\left(\frac{p'_{it}\cdot q_{it}}{\sum_i p'_{it}\cdot q_{it}} + \frac{p'_{it-1}\cdot q_{it-1}}{\sum_i p'_{it-1}\cdot q_{it-1}}\right)(\ln p_{it} - \ln p_{it-1})\right] \tag{2}$$

$$p_{it} = \chi_{it}\cdot p_{it}^{im} + (1-\chi_{it})p_{it}^{do} \tag{3}$$

$$p'_{it}\cdot q_{it} = p_{1t}\cdot q_{it}\cdot f_i / f_1 \tag{4}$$

(1) is the Divisia Composite Energy Price Index formula. (2) is the rate of change in Divisia energy prices for the current period. (3) is the composite price of the ith energy source for period t. (4) is the adjusted value of energy consumption in order to keep the value of energy consumption uniform in both energy and economic values. Table 1 presents the indicators and related explanations.

Table 1: Indicators and explanations

Indicator	Description
i=1,2,3	Coal, oil, natural gas
t=1,2,...,T	Successive yearly changes from 2001-2020
p_{it}	Composite price of energy source i in period t
q_{it}	Consumption of energy source i in period t
χ_{it}	External dependence of energy source i in period t
p_{it}^{im}	Import price of energy source i in period t
p_{it}^{do}	Domestic price of energy source i in period t
p'_{it}	Revised energy prices
p_{1t}	Coal prices in period t
f_i	Standard coal conversion factors for each energy source

2.2 Selection of proxy variables

Table 2: Price proxy variables

Variant	Variables of the agent
Coal prices	Annual average price of power coal at Qinhuangdao port, China
Oil domestic price	Annual average of China Daqing oil spot price
Oil foreign price	Annual unit-price weighted energy imports from 43 countries
Natural gas domestic price	Annual average price of natural gas for industrial use in 36 large and medium-sized cities in China
Natural gas foreign price	Annual average of weighted unit prices of piped natural gas and liquefied natural gas imports from 19 countries

According to the construction method of Divisia Comprehensive Energy Price Index mentioned above, we have to choose appropriate proxy variables to calculate. The proxy variables are selected on the example of prefecture-level cities in Shanxi Province.The energy price proxy variables are shown in Table 2.The energy consumption proxy variables are shown in Table 3.

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Table 3: Proxy variable for energy consumption

Variant	Variables of the agent
Consumption of coal	Quantity produced and used for internal consumption in prefecture-level cities in Shanxi province
	Quantity produced outside of prefecture level cities in Shanxi and used for internal consumption
Consumption of oil	Quantity produced and used for internal consumption in prefecture-level cities in Shanxi province
	Quantity produced outside of prefecture level cities in Shanxi and used for internal consumption
Consumption of natural gas	Quantity produced and used for internal consumption in prefecture-level cities in Shanxi province
	Quantity produced outside of prefecture level cities in Shanxi and used for internal consumption

For some prefecture-level cities, we cannot get data on coal oil and gas consumption, external dependence, etc. from statistical yearbooks or databases. This is the main problem encountered in the construction of energy price index for prefecture-level cities. In order to solve this problem, this paper adopts the downscaling method to impute the relevant data.

2.3 Down-scaling method

For cities with missing energy consumption and external dependence, this paper uses the down-scaling method for calculating consumption proposed by Yuli Shan et al.[7]

Provincial data such as energy consumption in Shanxi Province can be obtained from the Shanxi Provincial Statistical Yearbook.

Firstly, we define a ratio of a prefecture-level city to a province p.This city-to-province ratio can be chosen from GDP, CO2 emissions, secondary output, and other values related to energy consumption. In this study, the GDP, carbon dioxide emissions, and secondary production value of Shanxi Province from 2001 to 2020 are selected to correlate with the consumption of three energy sources, namely coal, oil, and natural gas. Specific indicators are selected according to the results.

$$P = Index_{city} / Index_{province} \times 100\% \tag{5}$$

Based on the provincial-to-municipal ratio P, we reduce the provincial energy consumption to the prefectural level.

$$Consumption_{city} = Consumption_{province} \times P \tag{6}$$

In the case of Shanxi Province, the annual consumption of coal, oil and natural gas in each prefecture level city can be projected.

2.4 Relevance Analysis

In this study, Spearman's correlation was used to analyze the relationship between three types of energy consumption and GDP, secondary output, and carbon dioxide emissions in Shanxi Province from 2001 to 2020.

Table 4 presents the results of the correlation analysis.The variable names in the table SI is the second output, GDP is the gross regional product, CO2 is the carbon dioxide emissions, Coal is the coal consumption, Oil is the oil consumption, and NG is the natural gas consumption.N is the sample size.

According to Spearman's correlation test it was found that the correlation between coal consumption and GDP was the most significant, they are correlated at 0.60,so this study adopts GDP as the downscaling indicator of coal consumption.

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Table 4: Correlation analysis

Correlations					
			SI	GDP	CO2
Spearman's rho	SI	Correlation Coefficient	1.000	.924**	.930**
		Sig. (2-tailed)	.	.000	.000
		N	20	20	20
	GDP	Correlation Coefficient	.924**	1.000	.958**
		Sig. (2-tailed)	.000	.	.000
		N	20	20	20
	CO2	Correlation Coefficient	.930**	.958**	1.000
		Sig. (2-tailed)	.000	.000	.
		N	20	20	20
	Coal	Correlation Coefficient	.593**	.600**	.574**
		Sig. (2-tailed)	.006	.005	.008
		N	20	20	20
	Oil	Correlation Coefficient	.772**	.756**	.717**
		Sig. (2-tailed)	.000	.000	.000
		N	20	20	20
	NG	Correlation Coefficient	.918**	.989**	.940**
		Sig. (2-tailed)	.000	.000	.000
		N	20	20	20
**. Correlation is significant at the 0.01 level (2-tailed).					

According to Spearman's correlation test it was found that the correlation between oil consumption and secondary production value is the most significant, their correlation was 0.772,so this study adopts the secondary production value as a downscaled indicator of oil consumption.

According to Spearman's correlation test it was found that natural gas consumption and GDP are most significantly correlated, their correlation is 0.989,so this study adopts GDP as a downscaling indicator for natural gas consumption.

In summary, this study utilizes the summation of the three Divisia energy price indices for coal oil and natural gas to obtain a Divisia composite energy price index at the prefecture level city scale. The exact process is illustrated in Figure 1.In this case, the proxy variable for energy consumption is obtained by downscaling the provincial energy consumption. The downscaled indicator for coal and natural gas is GDP, and the downscaled indicator for oil is the second value of production. The proxy variables for energy prices are shown in Table 2.

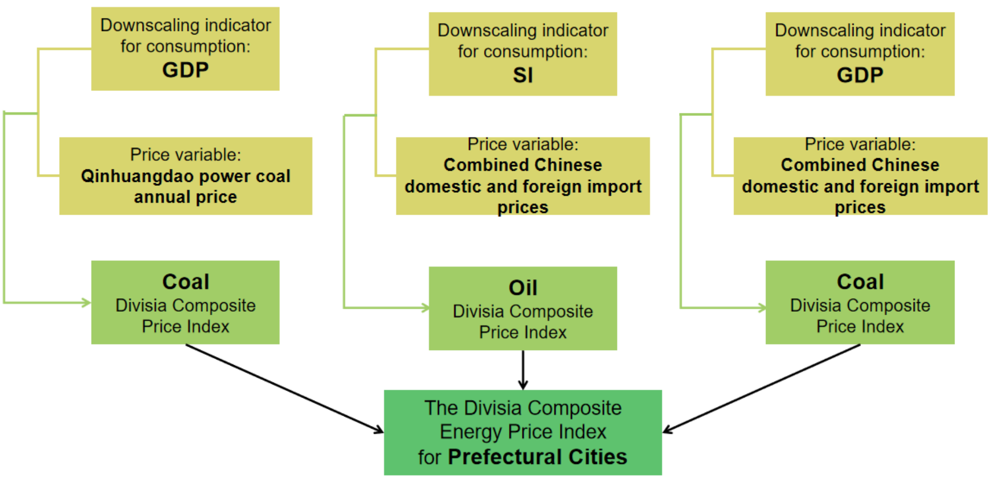

Figure 1: Construction of the Divisia Composite Energy Price Index for Prefecture-level Municipalities

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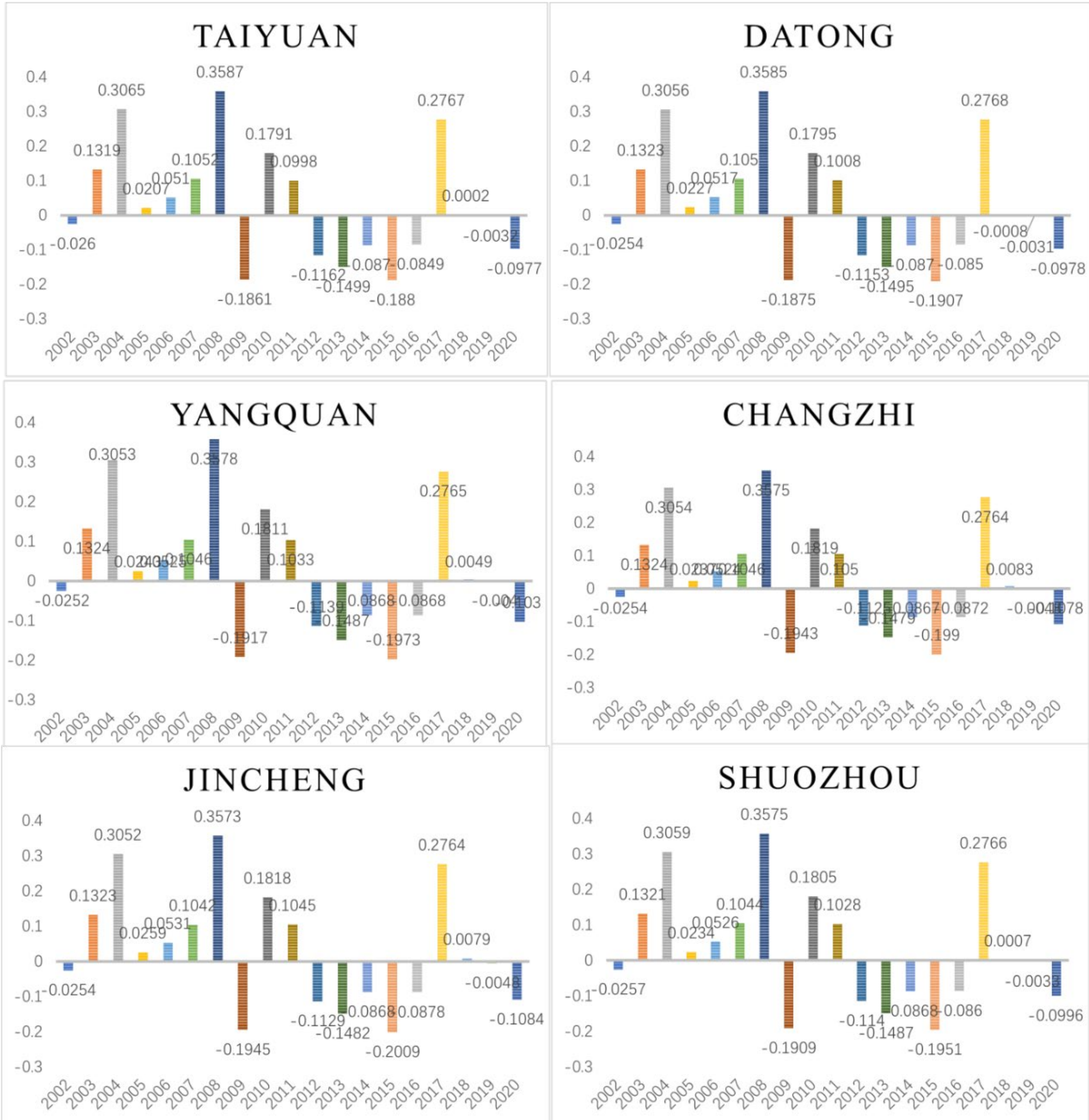
3. Result for Prefecture-level City in Shanxi

3.1 Results of Divisia Composite Energy Price Growth Rate by Prefectural Cities in Shanxi Province

Based on the results of Figure 2, it can be seen that the growth rate of Divisia's composite energy prices in the prefecture-level cities of Shanxi Province maintains the same increasing and decreasing trend every year. Among them, the increase in 2008 was the largest, with Taiyuan City having the largest growth rate of 0.3587; in 2009, the decrease in each prefecture-level city was the largest, with Luliang City having the smallest growth rate of -1.962.



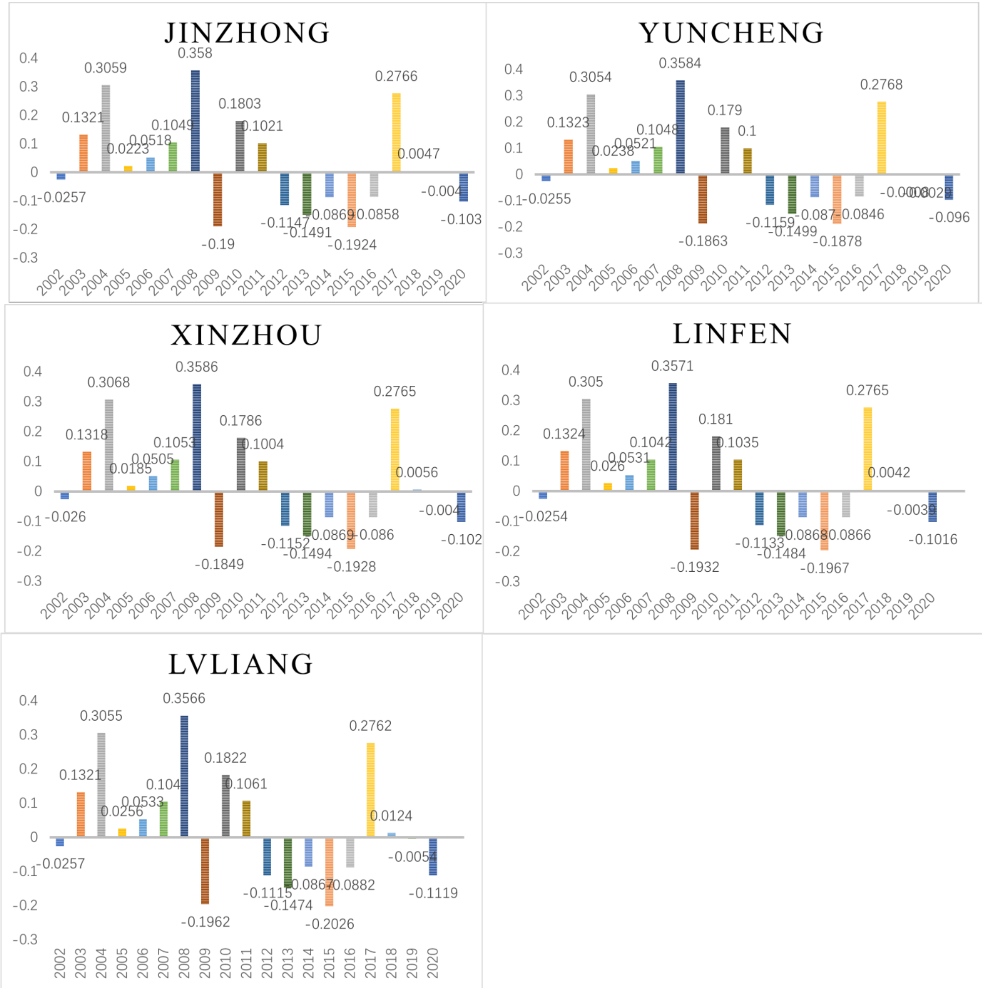


Figure 2: Divisia Composite Energy Price Growth Rate

3.2 Energy proportion of municipalities by prefecture

The results in Figure 3 show that the fluctuation trend of the share of total energy value after adjusting the calorific value of coal, oil and natural gas in eleven prefecture-level cities is consistent, with the share of coal decreasing from 72.37% in 2001 to 47.42% in 2020; the overall fluctuation of oil is larger, growing to 34% in 2009, and the fluctuation trend is stable after 2009, with a share of 28.59% in 2020; and the share of natural gas is stable in 2009, with a share of 28.59% in 2020. Upward trend after 2009, growing to 23.98% in 2020.

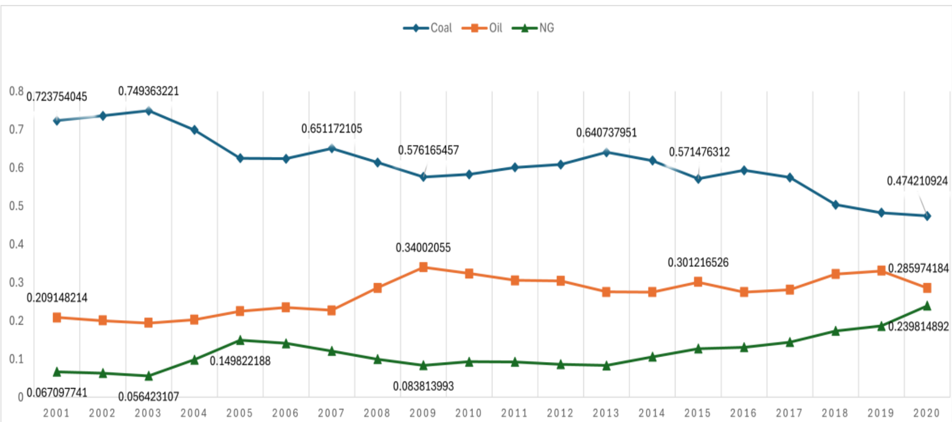


Figure 3: Proportion of coal oil and gas

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3.3 Results of the Divisia Composite Energy Price Index for municipalities at the prefecture level

As can be seen from the Table 5 and Figure 4, the trend of increase and decrease of the Composite Energy Price Index for each prefecture-level city in Shanxi Province is consistent every year, only the value changes due to the influence of factors such as the composition of energy consumption, etc. The increase of the Divisia Composite Energy Price Index was the largest for each city in 2008; and the decrease of the Divisia Composite Energy Price Index was the largest for each city in 2009.

The year 2001 was set as the base period with a value of 100.

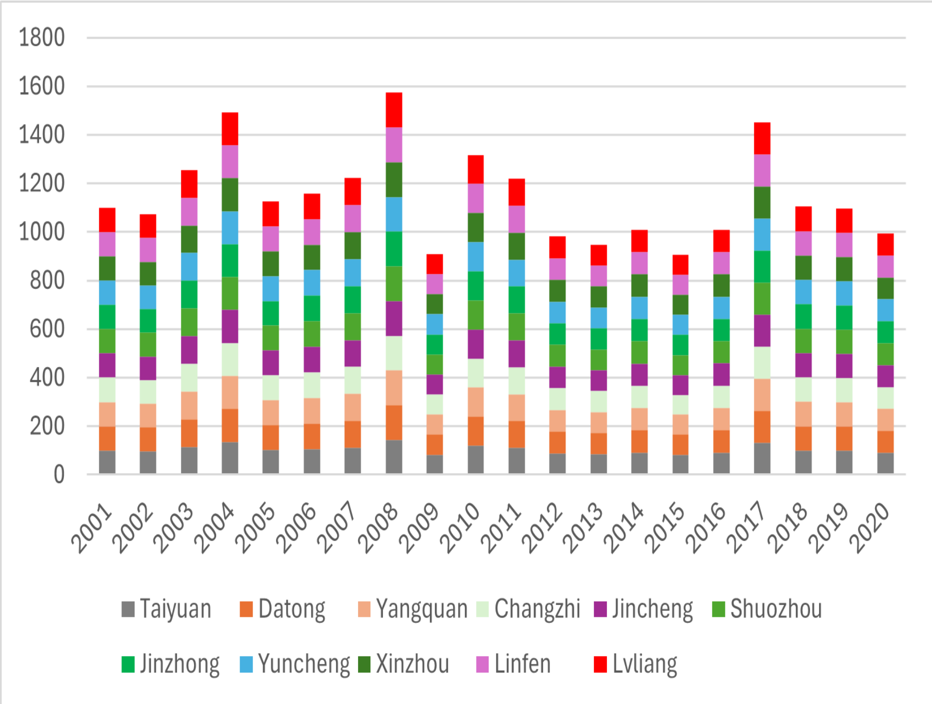

Figure 4: Divisia Composite Energy Price Index for Prefecture-level Cities in Shanxi Province

The Divisia Composite Energy Price Index for each prefecture level city from 2001 to 2020 is shown in the table below. The year 2001 was set as the base period with a value of 100.

Table 5: The Divisia Composite Energy Price Index for each prefecture level city from 2001 to 2020

	Taiyuan	Datong	Yangquan	Changzhi	Jincheng
2001	100	100	100	100	100
2002	97.43351	97.49199	97.51149	97.49199	97.49199
2003	114.0994	114.1451	114.1565	114.1565	114.1451
2004	135.8661	135.7439	135.7032	135.7168	135.6896
2005	102.0916	102.296	102.4598	102.3983	102.6238
2006	105.2323	105.306	105.3903	105.3797	105.4535
2007	111.0933	111.0711	111.0266	111.0266	110.9822
2008	143.1467	143.1181	143.018	142.9751	142.9465
2009	83.01906	82.90291	82.55545	82.34108	82.32462
2010	119.614	119.6619	119.8535	119.9494	119.9374
2011	110.495	110.6055	110.8824	111.0711	111.0155
2012	89.02971	89.10988	89.23472	89.35973	89.324
2013	86.07941	86.11384	86.18276	86.25174	86.22586
2014	91.66771	91.66771	91.68604	91.69521	91.68604
2015	82.86147	82.63805	82.09443	81.95499	81.79942
2016	91.86041	91.85123	91.68604	91.64938	91.5944
2017	131.8771	131.8903	131.8507	131.8375	131.8375
2018	100.02	99.92003	100.4912	100.8335	100.7931
2019	99.68051	99.69048	99.6008	99.52115	99.52115
2020	90.69209	90.68303	90.2127	89.78071	89.72686

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	Shuozhou	Jinzhong	Yuncheng	Xinzhou	Linfen	Lvliang
2001	100	100	100	100	100	100
2002	97.46274	97.46274	97.48224	97.43351	97.49199	97.46274
2003	114.1222	114.1222	114.1451	114.088	114.1565	114.1222
2004	135.7847	135.7847	135.7168	135.9069	135.6625	135.7303
2005	102.3676	102.2551	102.4085	101.8672	102.6341	102.593
2006	105.4008	105.3165	105.3481	105.1797	105.4535	105.4746
2007	111.0044	111.06	111.0488	111.1044	110.9822	110.96
2008	142.9751	143.0466	143.1038	143.1324	142.9179	142.8464
2009	82.62152	82.69591	83.00246	83.11874	82.43171	82.18478
2010	119.7816	119.7577	119.6021	119.5542	119.8415	119.9854
2011	110.827	110.7494	110.5171	110.5613	110.9046	111.1933
2012	89.2258	89.16336	89.05643	89.11879	89.28828	89.44914
2013	86.18276	86.1483	86.07941	86.12246	86.20862	86.29487
2014	91.68604	91.67688	91.66771	91.67688	91.68604	91.69521
2015	82.27524	82.49768	82.87804	82.46469	82.1437	81.66048
2016	91.75942	91.77778	91.88798	91.75942	91.70438	91.55777
2017	131.8639	131.8639	131.8903	131.8507	131.8507	131.8111
2018	100.07	100.4711	99.92003	100.5616	100.4209	101.2477
2019	99.67054	99.6008	99.71042	99.6008	99.61076	99.46146
2020	90.51994	90.2127	90.8464	90.30296	90.33908	89.41337

4. Conclusion

This study proposes a methodology for calculating the Divisia Composite Energy Price Index for prefecture-level cities based on the downscaling method. And the results of eleven prefectural-level cities under Shanxi Province are obtained from 2001 to 2020 as an example. Since the energy consumption of some prefecture-level cities is not available, the downscaling method, therefore, helps to project the energy consumption of prefecture-level cities.

The disadvantage of this study is that since the energy consumption of prefecture-level cities is projected, it may lead to unbalanced changes in the price index.

References

[1] Hubacek, K., Feng, K., Chen, B., 2011. Changing lifestyles towards a low carbon economy: an IPAT analysis for China. Energies 5, 22-31.

[2] Guan, D., Peters, G.P., Weber, C.L., Hubacek, K., 2009. Journey to world top emitter: an analysis of the driving forces of China's recent CO2 emissions surge. Geophys. Res. Lett. 36, L04709.

[3] Dhakal, S., 2009. Urban energy use and carbon emissions from cities in China and policy implications. Energy Pol. 37, 4208-4219.

[4] Liu, Z., Liang, S., Geng, Y., Xue, B., Xi, F.M., Pan, Y., Zhang, T.Z., Fujita, T., 2012b. Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites: the case of Beijing, Tianjin, Shanghai and Chongqing. Energy 37, 245-254. <Go to ISI>://WOS:000300465800028.

[5] Zhang Xiaobo. 1992. Theory and practice of the DIVISIA index. Statistical Research, (1): 41-45.

[6] Kang Jijun, Zheng Siyue. 2021. Can crude oil prices alone effectively measure energy market shocks. World Economy, 44(7):26.

[7] Mi Z, Zhang Y, Guan D, et al. 2016. Consumption-based emission accounting for Chinese cities. Applied energy, 184: 1073-1081.