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Economic Vulnerability of Mining City —A Case Study of Fuxin City, Liaoning Province, China

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Abstract: The economic system of mining city is of typical vulnerability characteristics that can be manifested by its high economic sensitivity and lack of response capacity to the gradual depletion of regional mineral resources. Taking Fuxin City of Liaoning Province as a case, this paper established an economic vulnerability assessment method integrating BP neural network with vulnerability index, then carried out an economic vulnerability assessment of Fuxin during 1989–2006. The results indicate that: 1) Affected by the gradual depletion of regional mineral resources, the economic development of Fuxin had kept high economic sensitivity from 1995 to 2001, and the response capacity to cope with and adapt to the impacts of the perturbation of mineral resources was weak and relatively lag. The evolution of economic vulnerability can be divided into three stages: in 1989–1994, the economic vulnerability of Fuxin City decreased slowly; in 1995–2001, the beginning stage of economic transformation, the economic vulnerability of Fuxin City went up rapidly; in 2002–2006, the economic vulnerability of Fuxin City descended and showed a trend to be stable. 2) The influence of economic sensitivity on Fuxin′s economic vulnerability is more evident than that of response capacity. 3) The decreasing supply of mineral resources and the simple industrial structure are main factors leading to the economic sensitivity of Fuxin. 4) The improvement of economic response capacity of Fuxin has typical characteristics of input-driven growth, and external assistance is of great importance to the rapid improvement of economic response capacity of Fuxin. And 5) the change from the simple industrial structure to diversified one of Fuxin is still unaccomplished, and the contribution of non-coal-based industry to local economic development is relatively limited.
Keywords: mining city; economic vulnerability; economic transformation; Fuxin City

1 Introduction

'Vulnerability', ever since the 1990s, is a scientific frontier theme for a variety relevant researches and disciplines such as global environmental change, hazards management, ecology, economics and geography, etc. (Janssena et al., 2006). It has become a new paradigm with important theoretical and methodological value in sustainable development (Zhang, 2007). The new emphasis on vulnerability marks a shift away from traditional scientific assessments, which limit the analysis on the stressors (e.g. climate change, hurricanes) and the corresponding impacts, towards an examination of the system being stressed and its ability to respond (Ribot, 1995). Over the last decade, several quantitative and semi-quantitative metrics of vulnerability have been proposed and applied in the social and global-change sciences, such as composite vulnerability indicators, overlay analysis of vulnerability map, vulnerability function model, fuzzy matter element analysis, etc. (Li and Zhang, 2008). The recent vulnerability research has moved from analyses focusing on either ecological systems or social system toward coupled man-land systems (Young et al., 2006; Li et al., 2008), and more attention was paid to social and economic dimensions. However, developing robust measures of vulnerability is still challenged by the lack of consensus on the exact meaning of the term and the complexity of the systems analyzed, and few studies in this realm focus on regional economic vulnerability, most of which center on the com-

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parative assessment of regional economic vulnerability, lacking further discussion on the mechanism, influencing factors, and evolution of it (Briguglio, 1992; 1993; 1995; Li and Zhang, 2008; Zhao and Zhang, 2006).

One of the surprising features of modern economic growth is that economies with abundant natural resources have tended to grow less rapidly than natural resources-scarce economies (Sachs and Warner, 1995), thus the relationship between the abundance of natural resources and the economic growth has been analyzed in a number of recent studies (Sachs and Warner, 2001; Aryee, 2001; Stevens and Dietsche, 2008). The odd feature has supported the view that natural resources abundance seems to be more of a curse than a blessing for economic development (Brunnschweiler, 2008). In China, a large number of mining cities have grown relying on the exploring and processing regional abundant mineral resources (Zhu, 2004). The economy in many mining cities, especially in the resources-exhausted mining cities, lags behind other cities (Fan et al., 2005). The high dependence on mineral resources has resulted in the simple industry structure of mining city, furthermore, urban economic system is very sensitive to the depletion of regional mineral resources. Meanwhile, long-time dependence on mineral resources has greatly limited the development of substitute industry, so mining city lacks of capacity to cope with and adapt to the depletion of regional mineral resources. The economic system of mining city is of typical vulnerability characteristics (Li and Zhang, 2008), which is the essential factor impeding the sustainable economic development of mining city. This paper takes a case of Fuxin City, the first experimental mining city for economic transformation in China, to analyze the evolution of economic vulnerability of Fuxin in 1989–2006, to discuss the main influencing factors and to find valuable coping policies to decrease the economic vulnerability and realize the sustainable economic development.

2 Study Area and Methodology

2.1 Study area

Fuxin City, located in the northwest of Liaoning Province, with an area of 10.3×10^3km^2 and a population of 1.92×10^6, is a typical mining city that coal resources are to be exhausted (Fig. 1). Because of the gradual depletion of regional coal resources since the 1990s, the annual GDP growth rate of Fuxin City decreased from 9.6% (1991–1995) to 2.1% (1996–2000), urban economy based on coal mining and processing had been greatly stroked.

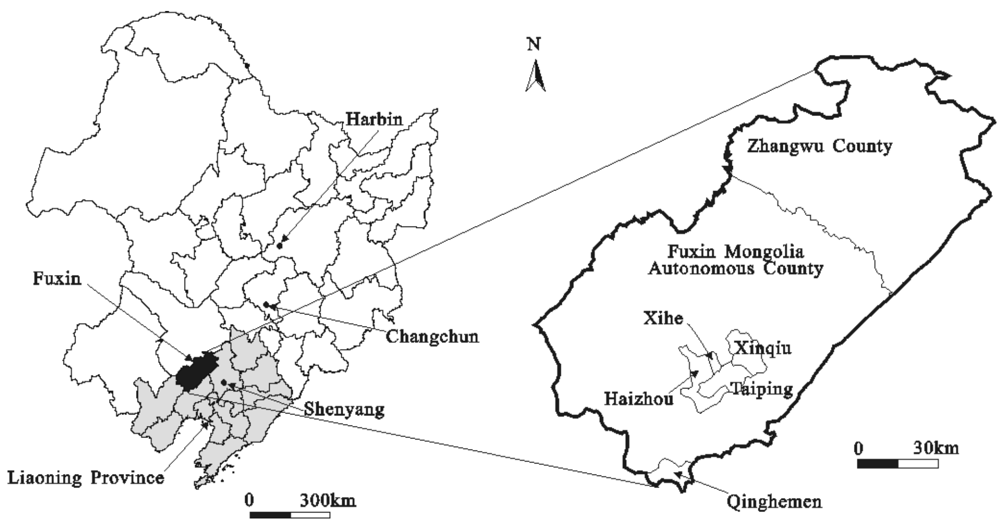


Fig. 1 Sketch map of location of Fuxin City in Northeast China

To advance the economic transformation of Fuxin City, local government attempted to develop the building materials industry, chemical industry and cotton spinning industry, but did not achieved remarkable effect. In 1995, modern agriculture was selected as a new substitute industry of Fuxin City, and the economic transformation began to have a clear and stable direction (Zhang, 2005). In recent years, especially after 2001 when Fuxin was designed as the first experimental mining city of China for economic transformation, local economy has kept a relatively rapid development. The annual GDP growth rate and local annual financial revenue growth rate achieved at 17% and 17.7% in 2001–2005, respectively. However, Fuxin City is still an underdeveloped region in Liaoning Province, whose GDP per capita was 8227 yuan (RMB), much lower than the provincial average level (21,974 yuan) in 2006.

2.2 Methodology

2.2.1 Conception of vulnerability

Vulnerability is an attribute to describe a system, subsystem, or system component which is prone to be harmed due to its sensitivity and lack of response capacity to perturbation acting on it (Li et al., 2008). It is an inherent property of system, which can be expressed by the system's sensitivity and response capacity when the system is exposed to the perturbation.

$$V=f(S, R) \quad (1)$$

where V is the vulnerability, S is the sensitivity of system, and R is the system's response capacity, including economic resilience and adaptation capacity.

2.2.2 Economic vulnerability assessment indicator system and data sources

Although vulnerability has been an important theoretical topic in global change research for more than a decade, there are still many challenges existing in measuring the vulnerability of inter and intra systems. There are not commonly accepted methods for weighing the indicators, and most of them often lead to a lack of correspondence between the conceptual definition of vulnerability and the metrics. BP neural network is a kind of artificial neural network learned by self-adjusting a set of parameters, using back propagation train algorithm to minimize the error between the desired output and network output. For the superior nonlinear simulation capability, it becomes a widely applied artificial neural network. In this paper, BP neural network is used for assessing the economic sensitivity and response capacity of Fuxin City, and then the economic vulnerability index is designed to integrate economic sensitivity and response capacity (Li and Zhang, 2008).

$$V_i=S_i/R_i \quad (2)$$

where V_i is the economic vulnerability degree of year i, S_i is the economic sensitivity index of year i, and R_i is the economic response capacity index of year i.

The economic sensitivity of Fuxin City to the depletion of regional coal resources can be manifested in two aspects. One is directly induced by the depletion of regional coal resources, which can be demonstrated by the growth rate fluctuation of GDP and the output value of coal resources-based industry. The other indirectly resulted from the recession of coal mining industry, which can be exhibited by the growth rate variation of local financial revenue, living level of the resident and total profits of enterprises. Thus five indicators are selected to measure the economic sensitivity of Fuxin City.

The economic response capacity of Fuxin City to the depletion of regional coal resources is influenced both by common economic growth factors and special properties of resources economy. According to the viewpoint from Classical Economic Growth Theory, Neo-classical Economic Growth Theory and New Economic Growth Theory, factors such as fixed assets, human capital, technology progress and consumption capability are selected to represent the economic response capacity of Fuxin City. Then in consideration of the special properties of resources economy, supply of coal resources, industry diversity index, growth elastic index of non-heavy industry and cross-region economic cooperation intensity are chosen to further signify the economic response capacity of Fuxin City (Miao and Wang, 2006). The indicators are shown in Table 1.

Table 1 Indicator system of economic vulnerability of Fuxin City

	Indicator
Sensitivity	S_1 GDP growth rate (%)
	S_2 Growth rate of output value of heavy industry (%)
	S_3 Growth rate of local financial revenue (%)
	S_4 Growth rate of per-capita disposable income of urban residents (%)
	S_5 Growth rate of total profits and taxes of enterprises (%)
Response capacity	R_1 Investment in fixed assets ($\times 10^8$ yuan (RMB))
	R_2 Percentage of employment in research agencies and technical service in total employees (%)
	R_3 Overall labor productivity ($\times 10^4$ yuan/person)
	R_4 Engle index of urban residents
	R_5 Output of raw coal ($\times 10^4$t)
	R_6 Industry diversity index*
	R_7 Growth elastic index of non-heavy industry**
	R_8 Volume of passenger transport ($\times 10^6$ persons)

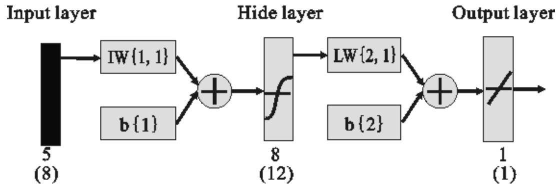
Notes: * Industry diversity index (D): $D=-\sum_{i=1}^{n} P_i \ln P_i$, where P_i is the share of output value of industry i to GDP, and n=3; ** Growth elastic index of non-heavy industry (G): G= growth rate of output value of non-heavy industry/growth rate of GDP

The study period is 1989–2006, and the data used for economic vulnerability assessment of Fuxin City were collected from *China City Statistical Yearbook* (Department of Urban & Social Economic Survey of National Statistics Bureau of China, 1989–2007) and *Fuxin Statistical Yearbook* (Fuxin Bureau of Statistics, 1995; 2001–2007).

2.2.3 Economic vulnerability assessment method

(1) Design of BP neural network

It has indicated that 3-layer BP neural network can approach precisely any continuum function (Kitahara et al., 1992), so two 3-layer BP neural networks are designed in this article. Economic sensitivity and response capacity indicators are used as input neurons of the two networks, and economic sensitivity index and economic response capacity index are the output neurons respectively, then try-error method is used for determining the node number of hidden layer (Lou and Wang, 2003). We get the topological structures of the two networks (Fig. 2). In the two networks, transfer function of hidden layer is *tansig*, transfer function of output layer is *purelin*, and performance function of neural network is *mse*.



IW{1,1} are weights to hide layer from input layer; LW{2,1} are weights to output layer from hide layer; b{1} are biases to hide layer; b{2} are biases to output layer; the numbers 5, 8 and 1 are the node numbers of 3-layer BP neural network for economic sensitivity assessment; the numbers 8, 12 and 1 in the brackets are the node numbers of 3-layer BP neural network for economic response capacity assessment

Fig. 2 Topological structure of two BP neural networks

(2) Train of BP neural network

According to the distribution characteristics of data used for economic vulnerability assessment, each indicator is divided into three ranges, representing low, middle, high standards for economic sensitivity and response capacity assessment respectively (Table 2). In each range, 200 equal interval samples are created by linear interpolation, and randomly selected 100 samples as testing samples (50) and validation samples (50), and the rests are used as train samples.

Table 2 Assessment standard for economic sensitivity and response capacity

	Grade classification of economic sensitivity				Grade classification of economic response capacity		
	Low	Middle	High		Low	Middle	High
S_1	[1.32,1.20)	[1.20,1.07)	[1.07,0.94]	R_1	[4.26,36.67)	[36.67,69.08)	[69.08,101.49]
S_2	[1.48,1.25)	[1.25,1.02)	[1.02,0.78]	R_2	[0.60,0.80)	[0.80,1.00)	[1.00,1.50]
S_3	[1.78,1.42)	[1.42,1.06)	[1.06,0.70]	R_3	[0.48,1.37)	[1.37,2.07)	[2.07,5.66]
S_4	[1.18,1.12)	[1.12,1.05)	[1.05,0.98]	R_4	(52.50,58.70]	(46.30,52.50]	[40.10,46.30]
S_5	[2.20,1.62)	[1.62,1.03)	[1.03,0.45]	R_5	[980,1333)	[1333,1426)	[1426,1616]
Desired output of BP neural network	[1,2)	[2,3)	[3,4]	R_6	[0.99,1.04)	[1.040,1.075)	[1.075,1.100]
				R_7	[–19.80, –4.20)	[–4.2,1.4)	[1.4,12.5]
				R_8	[10.10,12.40)	[12.40,24.55)	[24.55,26.85]
				Desired output of BP neural network	[1,2)	[2,3)	[3,4]

Considering the impacts of different algorithms on the convergence rate and performance of BP neural networks, in MATLAB's Neural Network Toolbox, *trainscg* and *learngdm* are selected as the training function and adaption learning function of the two BP neural networks. Then the weights and biases of the neural networks are initialized to small random values within the range [0, 1], loading the data files of train sample, testing sample and validation samples. After 4 and 27 epochs, the train errors of two BP neural networks achieve expected precision (*mse*<0.05), which indicates the generalization ability of the two BP neural networks has been well trained (Fig. 3).

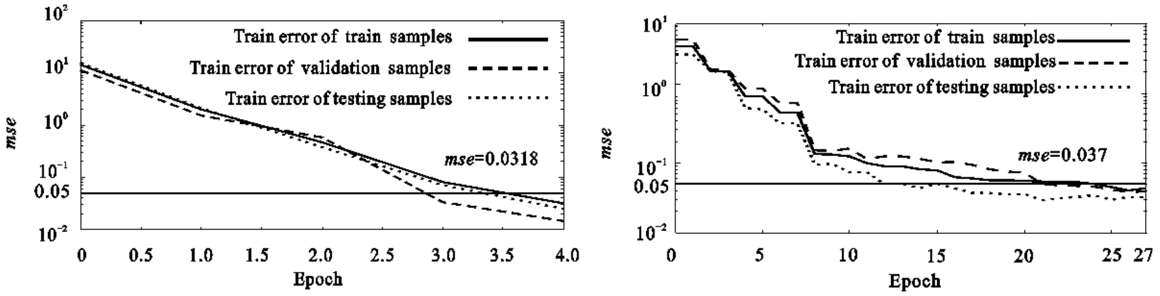
(3) Simulation and calculation of economic vulnerability index

After simulating the economic sensitivity index and economic response capacity index in the two well trained BP neural networks, economic vulnerability index could be calculated by Equation (2).

3 Results and Analyses

3.1 Evolution of economic vulnerability

As shown in Fig. 4, the economic vulnerability of Fuxin



0.05 is the expected *mse* of network, the *mse* of train samples after 4 epochs training is 0.0318
(a) BP neural network for economic sensitivity assessment

0.05 is the expected *mse* of network, the *mse* of train samples after 27 epochs training is 0.037
(b) BP neural network for economic capacity assessment

Fig. 3 Error performance of network training

City fluctuated noticeably from 1989 to 2006, which can be divided into three stages.

From 1989 to 1994, there was a slow decrease in the economic vulnerability of Fuxin City. During this period, the raw coal output had been remaining at about 1.35×10^6t per year, perturbation from the fluctuation of coal resources supply was relatively slight, most economic sensitivity indicators had been keeping a stable increase, and economic sensitivity was relatively low (Fig. 4a). During the same period, the economic response capacity of Fuxin City had a slight ascending trend (Fig. 4b), but all indicators influencing the economic response capacity, except the output of raw coal, were at a relatively low level, and the growth elastic index of non-heavy industry during this period was minus for most of time. The urban economic development highly depended on the mining and related industries, and economic transformation of Fuxin City was very slow.

From 1995 to 2001, economic vulnerability index of Fuxin showed a rapid increase trend (Fig. 4c). Central government of China strengthened the management on small coal mines during this period. Many small coal mines of Fuxin City were closed, and some leading coal mines such as Ping′an, Dongliang, Xinqiu were declared to be bankrupt successively due to unfavorable benefit. At the same time, the domestic coal market depression also struck local mining economy. Under the intensified perturbations from the rapid decrease of coal resources and the depression of domestic coal market, economic growth rate of Fuxin City was very slow and fluctuated noticeably, economic sensitivity kept rising to a very high level (Fig. 4a). Meanwhile, traditional coal-based industry declined rapidly, whose output decreased from 1.33×10^6t in 1995 to 0.99×10^6t in 2001. Moreover, affected by the successive droughts during this period, the contribution of modern agriculture to local economic development was limited, the impetus for urban economy development was weak, so the economic response capacity index continuously decreased and reached the bottom in 2001 (Fig. 4b). The change of economic vulnerability during 1995–2001 demonstrates that the resources based development mode of Fuxin City was of strong robustness, the ‘path dependence’ of economic development can be hardly changed in a short period. Under the perturbation from the gradual depletion of coal resources, the economic response capacity was relatively lag and inefficient, and urban economic development continuously showed a high sensitivity.

From 2002 to 2006, the economic vulnerability index of Fuxin City descended and showed a trend to be stable (Fig. 4c). After being designed as the first economic-transformation pilot city of China in 2001, Fuxin City got rid of 6-year economic stagnation. The annual GDP growth rate and local annual financial revenue growth rate maintained at 17.3% and 7.4% respectively during this period, other economic sensitivity indicators also kept at a relatively stable growth rate, and the economic sensitivity of Fuxin City descended rapidly compared to the period of 1995–2001 and kept at a relatively low level (Fig. 4a). At the same time, the economic response capacity went up dramatically. Fuxin City adjusted the output structure of coal resources, by which the increasing output of underground coal mine alleviated the intensity of perturbation from the depletion of open pit mine, and the output of coal increased from 1.21×10^6t in 2002 to 1.61×10^6t in 2006. Meanwhile, economic response capacity such as in the development of substitute industry, investment in fixed capital and high quality human resources, technique progress was strengthen.

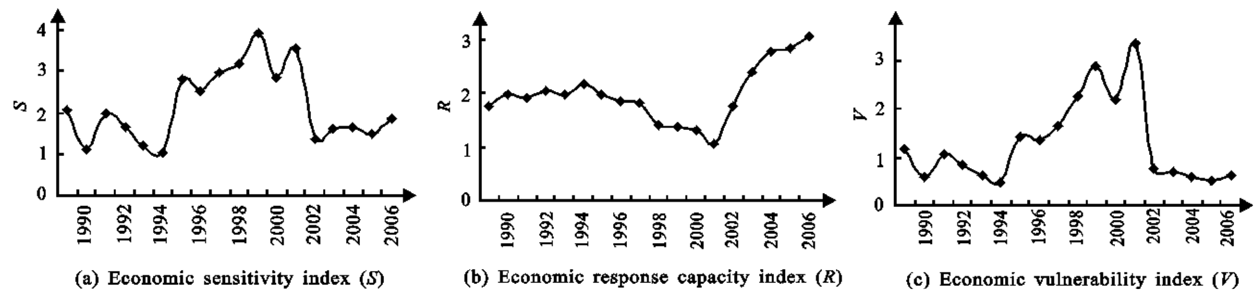


Fig. 4 Evolution of economic vulnerability of Fuxin City in 1989–2006

3.2 Main factors influencing economic vulnerability

The economic sensitivity index and economic response capacity index are two key variables for analyzing the economic vulnerability of Fuxin City, it can be seen from the assessment results that the variation of economic sensitivity index (coefficient of variation=0.43) was much higher than that of economic response capacity (coefficient of variation=0.27) during 1989–2006. Correlation analysis shows that the correlation between V and S was more predominant than the correlation between V and R (Table 3). So it can be concluded that the influence of economic sensitivity on Fuxin economic vulnerability was more evident than the influence of economic response capacity during 1989–2006.

The evolution of economic sensitivity during 1989–2006 reveals that the economic sensitivity of Fuxin City was closely related to the intensity of perturbation acting on it, of which the gradual depletion of regional coal resources was an important external factor influencing the sensitivity of economic system. Correlation analysis between economic sensitivity index and its indicators demonstrates that the GDP growth rate (S_1) and growth rate of output value of heavy industry (S_2) were more closely related to the economic sensitivity index than other indicators, and the simple economic structure attributed to the high dependence on coal resources which is the internal factor generating the sensitivity of economic system (Table 3). Meanwhile, it can also be seen from the correlation analysis that indicators, such as the growth rate of local financial revenue (S_3), growth rate of per-capita disposable income of urban residents (S_4) and growth rate of total profits and taxes of enterprises (S_5), were not significantly correlated to the economic sensitivity index, which implies that those indicators are less sensitive to the recession of mining industry.

Table 3 Correlation analysis between the economic vulnerability and its influencing factors

Influening factor	S_1	S_2	S_3	S_4	S_5	V
S	–0.756*	–0.749*	–0.20	–0.319	–0.085	0.916*

Influening factor	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	V
R	0.696*	0.762*	0.682*	–0.27	0.892*	0.459	0.163	–0.043	–0.810*

Note: * Correlation is significant at the 0.01 level

Correlation analysis between economic response capacity index and its indicators shows that the output of raw coal, investment in fixed assets, percentage of employment in research agencies and technical service in total employee and overall labor productivity were more closely related to economic response capacity index than other indicators. The result proves that the improvement of economic response capacity of Fuxin City during 1989–2006 was of typical input-driven growth characteristics, the impacts of other indicators were relatively limited due to their relatively slow development. In addition, the evolution of economic response capacity from 2002 to 2006 also implied that assistances from central government, such as finance, development projects, policies, played a very important role in strengthening the economic response capacity of Fuxin City.

4 Conclusions and Discussion

(1) Under the perturbation from the gradually depletion of coal resources, the economic development of Fuxin City had been exhibiting high economic sensitivity from 1995 to 2001, and the response capacity to cope with

and adapt to the impacts of the perturbation was weak and relatively lag. The mining economy was of typical vulnerability characteristics. According to the results of economic vulnerability assessment, the evolution of economic vulnerability can be divided into three stages: in 1989–1994, the economic vulnerability of Fuxin City decreased slowly; in 1995–2001, the beginning stage of economic transformation, the economic vulnerability of Fuxin City went up rapidly; in 2002–2006, the economic vulnerability of Fuxin City descended and showed a trend to be stable.

(2) During 1989–2006, the influence of economic sensitivity on Fuxin economic vulnerability was more evident than that of economic response capacity. The simple economic structure attributed to the high dependence on coal resources was the internal factor generating the sensitivity of economic system, and the gradually depletion of regional coal resources was an important external factor. The improvement of economic response capacity of Fuxin City was of typical input-driven growth characteristics, and the assistances from central government of China played a very important role in strengthening the economic response capacity of Fuxin City.

(3) The economic transformation of mining city would be a long process. As shown in the evolution of economic vulnerability of Fuxin City, the supply of coal resources is still a leading factor influencing the economic response capacity. The diversification of simple industrial structure of Fuxin City is far from accomplishment, the contribution of non-coal-based industry to local economic development is relatively limited.

(4) At present, the contribution of modern agriculture to regional economic development is relatively limited. To maintain the sustainable economic development of Fuxin City, it is necessary to make full use of the comparative advantage in coal resources and extend the coal-mine industry chain. However in the long run, with the increasing cost of underground coal mining, the contributions of local coal resources to regional economic development will gradually descend. Thus, the economic development of Fuxin City should reduce its dependence on local coal resources designedly and transfer the superfluous mining production capacity to other regions with abundant coal resources so as to alleviate the economic sensitivity to the output fluctuation of local coal resources. Meanwhile, it is urgent to enhance the economic response capacity to the gradual depletion of regional coal resources, including promoting the development of substitute industry to diversify the simple industry structure, strengthening the economic cooperation with central and coastal Liaoning urban agglomerations and eastern Inner Mongolia region, improving the urban environment to attract investment and human capital, and getting more preferential policies for compensating mineral resources, developing substitute industry, improving employment and social welfare, and restoring local physical environment, etc.

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