Energy price slump and policy response in the coal-chemical industry district: A case study of Ordos with a system dynamics model

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ABSTRACT

We employ system dynamics method towards a coal-chemical industry district economy evolution model, using coal industry, the coal-chemical industry, their downstream industries, and the manufacture-related service industry. Moreover, we construct energy price and policy response scenarios based on Ordos' management experience. The results show that the energy price slump had a negative impact on the overall economic development of the coal-chemical industry district, despite promoting non-resource industries. Furthermore, policies had different effects on the industry's output value and profit. In the long-term, developing alternative industries (AI) helps increase the industrial output value and profit. Decreasing value added tax (VAT) has immediate results and a distinctive effect on industrial short-term production value and profit, its long-term effect being limited. The effect of production limit (PL) on industrial profit is stronger than output value, and financial support (FS) is more conducive to improve the latter. However, coal mining and coal-chemical loan increases decrease the gross industrial profit level. Technology innovation (TI) has the best individual policy overall effect on production value and profits. Furthermore, the simultaneous implementation of PL, TI and AI can generate the synergy effect for each of them. And the simultaneous implementation of VAT and one or couple of other policies will generate the crowding-out effect both for VAT and other policies.

Keywords: energy price; policy response; coal-chemical industry district; system dynamics; scenario analysis

1. Introduction

Because environmental safety and energy security are gaining attention, the coal-chemical industry has

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become a hot topic (Zhou et al., 2012). China is coal dependent, a situation that is likely to persist. However, the carbon content of coal is also the highest among all fossil fuels. As such, a large number of pollutants, such as CO_2, SO_2 and nitrogen oxides produced by burning coal have become the main source of air pollution in China (Zhang et al., 2016), which exacerbated China's environmental crisis. Ecologically, the clean utilization of coal has become the general focus of government, academia, and industry (Tang et al., 2015; Mishra et al., 2014). Meanwhile, the recoverable oil reserves in China are much lower than the world average, and China's dependence on foreign oil import has reached 60% in 2015 and it is expected that China will become the largest oil importer by the early 2020s (van Moerkerk and Crijns-Graus, 2016). Therefore, for national energy security reasons, the government has launched a series of policies to promote the coal-chemical industry's development. For example, the Medium and Long Term Development Plan for Energy (2004-2020) and the thirteenth Five-Year Plan propose the coal-chemical industry as the strategic stress of China's medium and long-term energy development. Consequently, more than twenty large coal mining areas have constructed their coal-chemical industry bases by building industrial parks since 2006, their cumulative investment exceeding 600 billion yuan.

A mining area economic system is typically open and complex, containing several subsystems. In such a system, a small change in economic or environmental factors can trigger significant changes in mining area economy development (Martin, 2012; Martin and Sunley, 2014). Since the 2008 financial crisis, China's economic growth has gradually slowed, and the market demand for coal, oil, and coal-chemical products has also declined. The fluctuation of Morgan Stanley Capital International indices indicates that, compared to light industries, the energy industry, such as coal and oil industries, is more sensitive to macro-economic fluctuations, and the effects of macro-economic fluctuations on energy industry are larger. Coal and oil prices have continually decreased since 2012(shown in Fig.1(a) and 1(b)), causing massive losses in Chinese coal and coal-chemical industries and severe economic shocks to mining cities whose leading industries are the coal and coal-chemical industries. Furthermore, it has triggered a series of social problems, such as the dramatic increase in unemployment. The downturn of the coal market should be the low cost window period of coal-chemical products, but the comparative advantage of coal-chemical products has become increasingly weak due to the fall of international crude oil prices, which lead to the industry's deteriorating operating conditions (Zhang and Chen, 2014; Broadstock, 2014). For example, if coal price is 400 yuan per ton, the break-even point of coal-to-liquid (CTL) is oil at $60–80[2] per barrel. If the oil price fell to around $60 per barrel, the CTL project will suffer a loss. As the international crude oil price has fallen below $40 per barrel, Chinese coal-chemical industry giants, such as China Datang Corporation and China National Offshore Oil Corporation, have suffered heavy losses, and a large number of coal resource-based cities, such as Ordos, Hohhot and Yulin entered economic depression.

Here insert Fig.1. (a) and (b)

Given the serious impact of energy price shocks on economic fluctuations, many challenge-seeking researchers in academia and industry analyzed the relationship between energy price and economic growth (Scholtens and Yurtsever, 2012). Early studies of Darby (1982) and Hamilton (1983) identified that the rise of oil prices has a negative effect on economic growth. This is because the oil industry is fundamental to the national economy, and the rise of oil prices directly increase the costs and prices of related industries that use energy as primary raw material, and continue to spill over into downstream industries, which inhibit the macroeconomy, by affecting investment, consumption, and international trade. Subsequently, many scholars determined that the relationship between oil price shocks and economic growth has changed, and argued that the oil price-economy relationship was asymmetric (Lee and Ratti, 1995; Mork, 1994).After the 2008 global financial and oil price crises, the oil price-economy relationship become again a hot topic (Bhar and Malliaris, 2011; Broadstock et al., 2012; Ji and Fan, 2012; Ju et al., 2014). Meanwhile, studies focused on the oil price–economy relationship within certain countries (Ahmed et al., 2012; Cavalcanti and Jalles, 2013; Ghosh, 2011; Etornam and Denis, 2015; Oladosu, 2009).

Resource-based industries are those whose development depends on the exploitation of natural resources, and are predominant parts of their regional economic systems. The development of resource-based regions depends on and is subject to local resource reserves and displays different characteristics compared with other economic areas. Resource-based cities rise due to resources, but may decline due to resource depletion. Therefore, the sustainable development problem of resource-based regions is a subject of worldwide interest. Since H.A. Innis's seminal work on the economic growth of Canadian resource-based cities in the 1930s, researchers have continued and expanded his work to other research fields, including life-cycle of resource-based cities (Bradbury, 1988), health (Sharma and Rees, 2007), the resource curse hypothesis (Papyrakis and Gerlagh, 2007), economic transition (Li et al., 2013), and sustainable development (Creedy et al., 2006; Liu et al., 2012; Martinet and Doyen, 2007;Shen et al., 2005; Yu et al., 2008).

[2] The average exchange rate of the USD against yuan during 2015 is 6.2284.

Extant studies on the effect of energy price shocks and sustainable development policies of resource-based regions suffer from limitations, despite the fact that relative achievements provide a great referential value.

(1) Research content of previous literature mainly focuses on the relationship between oil prices and macroeconomy. The research about the impact of coal price shocks (especially the comprehensive coal and oil price shocks) on the economic system of resource-based regions is relatively rare (Ding al., 2016). Moreover, extant research on the sustainable development policy of coal mining areas is based on the depletion of natural resources, and the research on the response policies under energy price slumps are rare. The economic development of the coal-chemical industry districts is highly dependent on resources and particularly sensitive to energy price shocks (Rocchiet al., 2015), and its economic systems possess vulnerable characteristics (Constantinet al., 2015; Sun and Xiu, 2011). Therefore, exploring the impact of coal and oil prices shocks on the coal-chemical industry district and policy response is an interesting and challenging problem, and an important concern for government policy makers and business managers.

(2) From the methodology viewpoint, traditional models (e.g., vector autoregressive model, structural vector autoregressive model, vector error correction model, computable general equilibrium model, and dynamic stochastic general equilibrium model) assume that the evolution structures of economic systems are known, and reflect the dynamic process of economic development poorly, being difficult to convey uncertain behaviors of primary economic systems. Additionally, the information these methods can handle is limited (Juet al., 2014). Conversely, a system dynamics (SD) model combines qualitative with quantitative analysis and uses synthesis reasoning to describe these undefined behavioral characteristics. An SD model can describe the complicated connections among elements in different levels, and deal with dynamic processes with feedback in a system. Moreover, it can show the trends of complex system under different what-if scenarios, which is very useful in examining and recommending policy decisions in economic and social systems (Pattersonet al., 2004). Currently, SD has been widely applied in various research fields, such as economic systems (Zhanet al., 2012), ecosystems (Tian and Roderick, 2005), transport systems (Liu et al., 2015; Haghshenas et al., 2015), etc.

In this paper, we employ a system dynamics (SD) model to analyze the economic impacts caused by coal and oil prices shocks on the Chinese coal-chemical industry district, and the effect of different response policies on regional economic evolution. The rest of this paper is organized as follows: section 2 introduces the case study area, related data acquisition, and the coal-chemical industry district economy evolution model

(CIDEEM), and constructs energy prices slump and policy scenarios based on specific parameters; section 3 provides the output value and profit of coal industry, coal-chemical industry, and industries under different energy prices and policy scenarios; section 4 discusses the cumulative effect, synergy effect and crowding- out effect of each policy; and section 5 presents the main conclusions and policy implications, and identifies future research opportunities.

2. Methodology

Choosing Ordos as the case study area, we build a CIDEEM employing Vensim. Vensim provides causal tracing of structure and behavior, and has Monte Carlo sensitivity, optimization, and sub-scripting capabilities (Zhan et al., 2012). In this paper, results for the period 2016-2025 are analyzed, data from 2004-2015 is used to calibrate the model.

2.1. Case study area and data sources

Ordos (106°42'-111°27'E, 37°35'-40°51'N) is located in the southwest part of Inner Mongolia Autonomous Region of China, and covers an area of approximately 86,752 km^2. Ordos is the largest coal and coal-chemical industry base in China. In 2014, the proven coal reserves in this area reached 149.6 billion tons, which account for about 17% of the total coal reserves in China. Ordos has built its coal-chemical industry base consisting of Ulan Mulun, HuiNeng, DaLu, and ZhunGeEr industrial parks. The coal-chemical projects in Ordos cover many fields, such as coal-coking, coal-gasification, and coal-liquefaction. The main products of coal-coking are tar, coal gas, coke, and calcium carbide. Acetylene, Polyvinyl chloride (PVC), Polyvinyl alcohol (PVA), and Butanediol (BDO) can be obtained by further processing calcium carbide. The main products of coal-coking are oil substitutes, and the main products of coal-gasification include synthesis ammonia, hydrogen and ethyl alcohol. Hundreds of chemical products, such as olefin, formaldehyde, and acetic acid can be produced by processing ethyl alcohol. The leading industry chain of Ordos' coal-chemical industry, its downstream industries and the manufacture-related service industry are shown in Fig. 2.

Here insert Fig. 2

The data on Ordos' economy and society are derived from officially published statistics, including the Statistical Yearbook of Ordos (2005–2016), Yearbook of Ordos (2005–2016), Statistics and Development Communique of Ordos (2005–2016). The data on coal price, the logistics, and production coal industry costs come from China Coal Industry Yearbook (2005-2016) and the coal industry database of China Coal Market Online (http://www.cctd.com.cn). The data on oil price comes from the oil industry database of the China Energy Website (http://www.china5e.com).

2.2. System boundary and subsystem causal loop diagrams

The precondition of building an SD model is to clarify the system boundary (i.e., the composition of its subsystems). Therefore, the basic building blocks of the economic system of the coal-chemical industrial are defined first. Subsequently, we build four causal loop diagrams to analyze the characteristics of every subsystem and clarify the relationships of the main variables in the subsystems, and describe the mutual influences and interactional relationships among the subsystem's variables.

2.2.1 System boundary

According to Mathews and Tan (2011), Song and Li (2012), and Yao et al. (2015), Ordos' economic system consists of four subsystems, namely, coal industry, coal-chemical industry, their downstream industries, and the manufacture-related service industry, as shown in Fig.2.[3] The coal industry subsystem refers to the production system formed of coal mining and processing. The coal-chemical industry is the production system that uses coal as raw material, and transforms it coal into gas, liquid and solid fuel through chemical processing. The downstream industries subsystem refers to a collection of industries that use coal and coal-chemical products as consumer goods and their downstream industries, including electricity, building materials and other manufacturing industries. The manufacture-related service industry provides services and support to ensure that the three previous subsystems can operate and develop normally. The coal industry, especially the coal-chemical one are typically technology- and capital-intensive industries, and there exist a long distance from the producing to the sales areas. Therefore, this paper studies the supporting effect of the manufacture-related industry on the economic development of Ordos from three aspects: science and technology, financial, and logistics services.

[3] According to the statistical yearbook of Ordos from 2001 to 2014, the economic development of Ordos depends on the coal and its downstream industries. Since 2001, the share of the added value of the primary industry to regional GDP was always lower than 2%, and the share of the added value of the secondary industry to regional GDP was always higher than 70%. Additionally, the manufacture-related service industry is dominant in the tertiary industry, and the share of consumer services to the tertiary industry was lower than 15%. Therefore, the primary and consumer industries (e.g. catering industry, tourist industry, etc.) were not considered into the industrial system model of Ordos in this paper.

2.2.2 Coal industry subsystem

The causal loop diagram of the coal industry subsystem is shown in Fig. 3(a). The total profits of coal industry are determined by total revenue and costs, the former being determined by coal price and coal sales, while the latter includes production, inventory, logistics, and other related costs. Coal sales are determined by coal output, the inventory of coal industry and the proportion of coal sales,[4] reflecting the positive effects of coal output on total profits. The production, inventory, and logistics costs are determined by coal output and the tax policy. The more the coal output, the higher the production cost, and the inventory and logistics costs of the coal industry are reflecting the negative effect of coal output on total profits. According to the Cobb-Douglas production function, the coal output is determined by the science and technology levels, the human capital and the productive capital investments, and is also affected by the policy production limit. The higher the total profits, the more the human and productive capital investment are, and the more the coal output and output value of the coal industry, reflecting the positive effect of the total profits increase on coal output.

2.2.3. Coal-chemical industry subsystem

The causal loop diagram of the coal-chemical industry is shown in Fig. 3(b). The coal-chemical industry's causal loop is similar to that of the coal industry. Specifically, the lower the price of coal as the raw material of the coal-chemical industry, the lower the production cost is, and the stronger the profitability of the coal-chemical industry. Meanwhile, the price of coal-chemical products are affected not only by market supply and demand, but also by oil price. When oil price is high, the price of coal-chemical products increases correspondingly. When oil price is low, the comparative advantage of coal-chemical products is weaker, and the coal-chemical industry's profitability declines correspondingly.

2.2.4. Downstream industries subsystem

The downstream industries' causal loop diagram is shown in Fig.3(c).As there are many types of downstream industries, and their product sales are mainly in other regions, we simplified the downstream industries causal loop, and their total profits are determined by total revenue and costs. Under certain market demand conditions, lower the prices of coal and coal-chemical products mean a stronger profitability of the

[4] The proportion of coal sales refers to the ratio of annual coal sales account for the total amount of coal available for sale. This indicator was used to reflect the supply and demand situation of external coal market.

downstream industries, and greater their profits. In turn, more profits result in stronger motivation and greater ability to expand reproduction, increasing the output of these industries.

2.2.5. Manufacture-related service industry subsystem

The manufacture-related service industry' causal loop diagram is shown in Fig. 3(d). First, the total industrial output value increase can cause more financial institutions to settle down, which can increase the local capital supplies, and subsequently increase the capital investment in coal and coal-chemical industries, and the total industrial value[5]. Second, the development of regional economies contributes to the increase of government revenue and the firm's financial strength, the government and enterprises' investment in technology development, and improving the regional innovation ability. In turn, the scientific and technological level improvement can enhance regional industry competitiveness by promoting product quality, the upgrade of industrial structure, and the improvement of labor productivity, and subsequently increasing the total industrial value. Third, the development of regional economies will increase the demand for logistics, which can drive transportation infrastructure construction and freight transportation industry development, and improve the logistics service level. Additionally, the improvement of the logistics service level can reduce the transportation costs of the related industries, promote coordinated development among them, and improve the regional economy's running quality.

Here insert Fig.3. (a), (b), (c), and (d)

2.3. Flow diagram

[5] Under the Chinese specific system background, the official performance evaluation mechanism with GDP as the core and financial decentralization system make the local government has a very strong incentive to invest in industries with a high return to achieve better performance (Wang et al., 2011). Meanwhile, the large-scale coal enterprises (such as Shenhua group, Mengtai group, etc.) are all state-controlled. During the process of market reform in China, the market processes of traditional capital-intensive industries (such as coal industry) are relatively slow. In order to maintain the "strong influence" of state-owned enterprises in these industries, the government retained a large number of administrative intervention in these enterprises, which makes the government and enterprises have strong political ties and exchange of interests. Under the background of overcapacity, in order to avoid the rapid decline in regional GDP which is unfavorable for the official performance evaluation and social instability caused by coal enterprises bankruptcies, the government will undertake various coordination to help the coal enterprises to get financial support (Zhang et al., 2017).

Although the causal loop diagrams describe the basic structure of feedback relationships, it does not distinguish the differences among various variables. Therefore, we build the stock-and-flow diagram for Ordos' industrial system using Vensim to explain the accumulated reactions for different variable levels, as shown in Fig.4.The CIDEEM consists of four subsystems and includes 8 level variables (L), 11 rate variables (R), and 65 auxiliary variables (A). Specific equations are shown in Appendix A.

Here insert Fig. 4

It is necessary to determine the parameters of each equation when the system dynamic method was used to simulation and analysis. In this paper, these parameters are determined using the following statistical methods:

(1) Arithmetic average method. Parameters are determined using historical data to calculate the arithmetic averages, including the population growth rate, mortality rate, the number of science researchers per total population, the number of financial practitioners per total population, the number of logistics practitioners per total population.

(2) Regression analysis method. Parameters are determined using linear-regression analysis with SPSS20.0, including the elastic coefficients of coal/coal-chemical industry's human and production capital investments, the influence coefficients of coal industry's total profit on its human and production capital investments, the influence coefficients of finance service levels on coal/coal chemical industry's human and production capital investment, the influence coefficients of coal-chemical industry's total profit on human and production capital investment, coal consumption of unit coal-chemical products, coal consumption of unit downstream industries output value, oil consumption of unit downstream industries output value, etc.

(3) Table function method. For the variables with no-linear relationships and exogenous variables, we adopt the table function method to determine the related parameters, including coal price, oil price, production limit, the rate of value added tax, etc.

2.4. Model tests

The model is just an abstraction of the real-world system. Therefore, whether the model can represent the real-world system properly or not determines the quality of model simulation and strategy analysis. It is necessary to test the validity of the model before the simulation test using authenticity, dimensional consistency, and sensitivity tests. Vensim was used to conduct the dimensional consistency test. Although there were some parameters with no realistic meaning, the model could still maintain dimensional consistency.

The authenticity test analyzed the error rate for 9 main variables of numerical changes between simulation and reality (Table 1).The results show that the error rate for 9 main variables of numerical changes between simulation and reality are no more than 10%, the fitting degree of the model being high, and can be used to simulate.

Here insert Table 1

To realize optimal control of the system and determine which parameters in the system have subtle effects on the system's behavior, we carry out a sensitivity test (shown as Table 1 in Appendix B). As observed from the results of the sensitivity analysis, the annual growth rate of production limit and the rate of added-value tax have greater influence on the total coal industry profit; the annual growth rate of financial investment, the coefficient of R&D investment, and coal price have greater influence on the output value and total coal industry profit. In the coal-chemical industry subsystem, coal price has a major influence on the total coal-chemical industry profit; the annual growth rate of financial investment, the coefficient of R&D investment, and crude oil price have greater influence on the output value and total coal-chemical industry profit. In the downstream industries subsystem, the crude oil and coal prices have greater influence on the total downstream industries profit; the annual growth rate of output value of downstream industries has major influence on output value and total profit. The above elements represent the potential variables that need to be investigated further.

2.5. Energy price and policy scenarios

2.5.1 Energy price scenarios

In order to explore the influence of coal and oil price decrease on the coal-chemical industry district, according to the current situation of China's macroeconomy, coal and coal-chemical industries, and the existing research on coal and oil price forecasting (Liu and Wu, 2015; Zhang et al., 2015; Zhao et al., 2015; Zhou et al., 2015), we establish three scenarios for coal and oil prices and a comprehensive price scenario. Specific technical parameters are shown in Part A of Table 2.

(1) Coal price slump scenario. Since January 2015, issues covered by the rapidly growing economy, such as excess capacity, environmental disruption, the imbalance of industrial structure, and the real estate bubble, have been exposed due to the slower economic growth of China. With the decline in market demand for steel and building materials, and the increased efforts on energy saving and emissions reduction, the condition of coal industry oversupply will not change shortly. Consequently, we expect the coal price in

China will remain low and may fall further. Therefore, with the coal price in 2015 as the baseline scenario, the coal price slump scenario estimates it will fall 5% annually after 2015.

(2) Oil price slump scenario. Affected by the shock of America's shale-gas, the international oil price continued to fall since 2014. Traditional oil-producing countries, such as OPEC, did not cut their output in order to maintain their market share, which resulted in international oil oversupply. As of December 2015, WTI crude oil price had fallen to $40 a barrel. Since the conflict between supply and demand in the international crude oil market cannot be eased in a short time, we expect oil price to remain low for some time and may fall further. Therefore, taking the oil price in 2015 as the baseline scenario, the oil price slump scenario estimates it will fall 5% annually after 2015.

However, the energy price cannot fall indefinitely, and the lowest prices of coal and oil from 2004 to 2015 were 305 yuan per ton and $31.5 a barrel, respectively. Therefore, we set 300 yuan per ton and $30 a barrel as the minimum thresholds of coal and oil prices, from where the price cannot fall further.

2.5.2 Policy scenarios

Main policy tools responding to the energy price decrease can be divided into three categories: the policies aimed at reducing the operating costs of energy firms, which reduce the tax burden and inventory costs by reducing the rate of value-added tax and production limit, respectively; the policies aimed at enhancing the level of services, which improve the service level for coal and coal-chemical industry development by enlarging inputs in finance, science, and technology; and the policies aimed at giving impetus to industrial transformation and restructuring, which cultivate alternative industries, such as electricity and advanced manufacturing. Based on the results of the sensitivity analysis, government documents, and extant researches, we established five individual policy scenarios. Specific technical parameters are shown in Part B of Table 2.

(1) Reducing the value-added tax of coal enterprises. In recent years, the government has introduced a series of tax break policies for coal industry. Issued by the state council in November 2013, *The guidance on promoting the smooth operation of coal industry* clearly established various arbitrary charges and indiscriminate collection of funds must be banned. The *Relevant measures on promoting the sustainable and healthy development of coal industry in the region*, released by the government of Inner Mongolia autonomous region also proposed that the coal price regulation fund standard and coal mine maintenance cost be reduced. The value-added tax is the biggest tax of coal enterprises, the annual value-added tax payable accounts for more than 50% of the total tax payable. During the annual meeting of National

People's Congress and Chinese People's Political Consultative Conference in 2016, delegates suggested that the rate of value-added tax should be reduced from 17% to 13%. According to the report released by China Securities Journal in March 2016, the treasury is researching the subject of value-added tax reform and will introduce relevant policies in the near future. Consequently, we designed the scenario of reducing the value-added tax for coal enterprises.

(2) Production limit. The root cause of the coal industry's issues is the imbalance between supply and demand caused by excess capacity. According to the *Statistical bulletin of national economic and social development in 2015* released by National Bureau of Statistics, the coal capacity of China in 2015 was 5.7 billion tons, and the coal consumption was 3.965 billion tons. The total inventories of the Chinese coal enterprises have been more than 0.4 billion tons in 2015. The State Council introduced the newly revised *Measures for the management of coal mine production capacity* in July 2014, and issued a series of policies, such as the *Decision on the cancellation and adjustment of a number of administrative examination and approval items* and the *Notice on containing the over-capacity production of coal mine and regulating the production behavior of enterprises* in August 2014, which required Ordos to limit 0.03 billion tons coal in 2015. As China's economic growth in 2016 is expected to decline,[6] the coal consumption expectation will be reduced further. Therefore, the production limit will be further increased.[7] Consequently, we designed Ordos's production limit scenario.

(3) Improving financial service. The decline of steel industry profitability, building materials industry, and the interrelated manufacturing industries led to the sharp increasing of coal enterprises' accounts receivable. To ease the pressure of coal enterprises' capital turnover and promote coal industry's healthy development, many government departments, such as National Energy Administration and Ordos government, have introduced many financial support policies since March 2015. *The government work report of Ordos*, released on January 26, 2016, established that the added value of financial industry accounts for regional GDP should be increased to over than 5% by 2020.[8]Consequently, we designed Ordos's financial service

[6]On March 5, 2016, the *government work report* released by the State Council established that the growth rate of GDP in 2016 should be stable between 6.5% and 7%, which is lower than the average GDP growth rate (7.8%) for the past five years.

[7] On February 1, 2016, the State Council released the *Comments on the coal industry to resolve overcapacity and realize a turnaround development* established that the capacity of the coal industry will be reduced by about 0.5 billion ton and be restricted 0.5 billon ton further from 2016.

[8]http://www.ordos.gov.cn/dtxx/jrordos/201502/t20150209_1334076.html

improvement scenario.

(4) Increasing the science and technology investment. The development of coal and coal-chemical industries in China rely on increasing the factors of production's input. The capacity and intensity of industrial scientific and technological innovation and the motivation for self-improvement are not enough. In order to reduce the production costs of the enterprises and improve the quality and added value of their products, the Chinese government is encouraging research and development in sectors that contribute to energy sources (Sun and Anwar, 2015). *The government work report of Ordos*, released on January 17, 2016, establishes that the R&D investment accounts for regional GDP should be over 2%. Consequently, we designed Ordos's science and technology service improvement scenario.

(5) Developing alternative industries. The function and orientation of many coal mining areas such as Ordos are limited to the framework of China's energy industry base, which decreased the diversity of regional industries and restricted the regional sustainable development. Therefore, Ordos took the non-resource-based industry as the breach of structure adjustment and transformation promotion. *The government work report of Ordos*, released in March 2015, established that "developing the manufacturing industries such as automobile, coal machinery, and electronic equipment, and realizing the added-value of non-resource based industry exceeded 100 billion yuan."[9] Consequently, we designed Ordos's alternative industries development scenario.

Here insert Table 2

3. Results

3.1 The impact of coal and oil price slump

The effects of different prices slump on coal industry's output value and profit are shown in Fig. 5(a) and (b). In the CPS scenario, the coal industry's output value and profit fall sharply, but the changing trends are different. Specifically, as the coal prices fall, the coal industry's output value shows a declining trend until 2022, and then a slightly upward trend. It is because that the coal industry's output value was determined by the coal price and output. On the one hand, the fall of coal price will decrease the output value of coal industry. On the other hand, for the coal-chemical industry and downstream industries, the decline of coal price can reduce their procurement cost. They will have more money for expanded reproduction, and the coal consumption of them

[9] This work report comes from the Ordos government website(http://www.ordos.gov.cn)

will increase, which will stimulate the coal production. However, for the profit of coal industry, it falls constantly as the coal prices fall. The main reason for this phenomenon is that the profit of coal industry was determined by the coal price, sales and costs. The sustained fall of coal price will decrease the revenue of coal industry. When the coal price fell below the cost price, the profits of coal industry will be negative. And this situation will not turn around until the coal price rises again. In the OPS scenario, the coal industry's output value and profit are slightly lower than that in the BS scenario, but the effect of the oil price slump on the coal industry is not significant in general. This is because the proportion of the coal-chemical industry's output value in the Ordos's total industrial output value is not very high, and the decline in coal demand due to the oil price slump has little influence on the coal industry. In the SPS scenario, the coal industry profit and output value are the smallest.

The effects of different prices slump on coal-chemical industry's output value and profit are shown in Fig.5(c) and (d). In the CPS scenario, the coal-chemical industry's profit and output value are the largest, and these two indicators demonstrated steady growth trends. This result indicates that the coal price slump has a negative influence on the coal industry, but can promote the coal-chemical industry development by reducing its production costs. In the OPS scenario, the coal-chemical industry's profit and output value are lowest, and the output value falls sharply and barely decreases after 2017; however, the profit displays a downward trend. In the SPS scenario, the coal-chemical industry's profit and output value falls in between the two scenarios, the changes being similar to the OPS scenario.

The effects of different prices slump on downstream industries' output value and profit are shown in Fig. 5(e) and (f). In the SPS scenario, the downstream industries' profit and output value are largest, which indicates that the slump of coal and oil prices can promote the development of these industries by reducing their production costs. The growth rate of the downstream industries' profit and output value is faster in time. Additionally, the downstream industries' output value and profit in the CPS scenario are better than those in the OPS scenario. This is because the thermal power industry has the largest proportion of downstream industries that use coal directly as consumer good and are more sensitive to the coal price slump.

The effects of different prices slump on total industrial output value and profit are shown in Fig. 5(g) and (h). In the SPS scenario, the total industrial output value and profit are smallest. The total industrial output value and profit in the CPS scenario are lower than those in OPS scenario, which indicates that the coal price slump has greater influence on Ordos' economy. Although the coal price slump contributes to the development of the coal-chemical and downstream industries, the benefits cannot counteract its negative effects on the coal industry because their proportion is lower than that of the coal industry. Additionally, In the CPS scenario, the total industrial profit falls sharply until 2021. In the OPS scenario, the total industrial profit is relatively stable, with a slightly downward trend.

Here insert Fig.5. (a), (b), (c), (d), (e), (f), (g), and (h)

3.2. The effect of response policies

The effects of different policies on coal industry's production value are shown in Fig. 6(a). In the TI scenario, the production value is the largest, and rises constantly. In the VAT scenario, the production value is the smallest but still higher than that in the SPS scenario. The output value of the coal industry improved in different degrees with time in the FS, AI and PL scenarios. Through the above scenarios, policy TI is a highly effective way to increase output value, while the effect of VAT is the worst. The effects of different policies on coal industry's profit are shown in Fig. 6(b). In the VAT scenario, the industry' profits had the largest increase of all individual policies. However, it declines sharply with time. In the long-term, the TI's contribution to increase the profits of the industry is the greatest. The profit of the coal industry improved in different degrees with time in the AI and LP scenarios. Moreover, the profit increases in the FS scenario are the worst among all policies, and this policy worsens the already affected industry's profit-making capacity. This phenomenon indicates that under the background of the decline in coal prices and market demand, if more money flows into coal production area, the imbalance between supply and demand will be aggravated, and the coal industry's profitability will be further weaken.

The effects of different policies on coal-chemical industry's production value and profit are shown in Fig. 6(c) and (d). A comparison between Fig. 6(c) and Fig. 6(a) shows that the change in coal-chemical industry's production value is similar to that of the coal industry in every policy scenario. According to Fig. 6(d), as for improving the profitability of the coal-chemical industry, the effect of TI is the best, FS is the worst, and VAT has no effect. Furthermore, comparing the profit level in the SPS, FS scenario leads to the further deterioration of the coal-chemical industry, and TI and AI not only improve the industrial situation, but also help the industry to make profit instead of suffering a loss.

The effects of different policies on downstream industries' output value and profit are shown in Fig. 6(e) and (f). A comparison of these two figures shows that the effects of the various policies on the downstream industries' output value and profit are similar. Specifically, in the AI scenario, the production value and profit of the industry have the largest increase among all individual policies, and maintains a higher level until 2025. In addition, TI and FS, both from the industry's output value and profit, contribute to the development of these industries. In LP and VAT scenarios, the changes of production value and profit are not significant.

The effects of different policies on Ordos' gross industrial output value and profit are shown in Fig. 6(g) and (h). The results show that TI and AI contributions are superior to the other policies. However, in the FS scenario, although the gross value of industrial output maintains year-on-year growth, the gross profit has the largest decline of all individual policies. In the VAT scenario, the improvement in gross production value, especially in gross profit, happens earlier and is initially greater. However, it appears with time. Finally, PL can significantly improve the total industrial profit while slightly enhancing the total industrial output value of Ordos. Thus, implementing PL is beneficial to the economic recovery and can improve the quality of economic development, rather than leading to regional economic stagnation and downturn.

Here insert Fig.6. (a), (b), (c), (d), (e), (f), (g), and (h)

4. Discussion

4.1 The cumulative effect of policies

To discuss the effects of the VAT, PL, TI, FS, and AI scenarios on industrial output value and profit, the simulated time was divided into two periods: 2016–2020 and 2021–2025. Specific cases are shown in Fig. 7.

The comparisons of Fig. 7(a) and (b), (c) and (d) show that, for the coal and coal-chemical industries, the cumulative effect of FS on the industrial production value is incremental, while its cumulative effect on industrial profit is diminishing. For the other industries, the FS contribution to the increase of output value and profit is accelerated, as shown in Fig. 7(e) and (f). For the overall industrial status, despite the comprehensive effect of the FS scenario on profit being negative, the negative effect is weakened in the second period.

The comparisons of Fig.7(g) and (h) show that, among all individual policy scenarios, TI always has the best effect on industrial output value and profit. The simulation results also demonstrate that AI's contribution to production value and profit of in the second five-year period is superior to that in the first period. The above phenomena reflect that the TI and AI policies have a certain lag time before they becomes effective. Therefore, TI and AI will play more important roles in Ordos' economic revival and healthy future development.

Although the VAT policy takes effect quickly, its effect on the improvement of production value and profit in the second five-year period is weaker than in the first five years. In the short run, the VAT policy will help lessen the severity of Ordos' economic downturn, but its effect maybe limited for a long time.

The coal industry's output value and profit in the PL scenario in the second five-year period is significantly higher than that in the first five-year period, while to both coal-chemical and other industries the cumulative effect of the PL scenario is decreasing in the long-term. Consequently, in the PL scenario, the whole industrial state has a positive tendency, as seen in Fig. 7(g) and (h). Additionally, comparing Fig. 7(b) and (a), PL's contribution to industrial profit is superior to the output value, indicating that the role of PL in promoting the quality of economic development is more significant.

Here insert Fig.7. (a), (b), (c), (d), (e), (f), (g), and (h)

4.2. The crowding-out and synergy effects of policy implementation

According to the analysis in sub-section 3.2, each policy can help to increase the output value whether of the individual industry or the whole industry in Ordos, and TI, AI, PL and VAT have positive effects on Ordos' gross industrial profit. Despite these policies can improve the total industrial profit in a certain degree, the function mechanisms of them on the improvement of total industrial profit are different from each other. Specifically, the implementation of PL can reduce the inventory costs of coal industry by cutting their inventory, and the profit of coal industry can be increased. Policy TI can improve the product competiveness and labor productivity by raising the science and technology level, and the production costs of related industries can be reduced. Policy AI can not only improve the profit of downstream industries, but also improve the coal industry's profit by increasing their coal consumption. And the implementation of VAT can improve the coal industry's profit by reducing its tax bearing directly.

As the analysis above, because of the function mechanisms of these policies on the improvement of total industrial profit are different from each other, the implementation of one policy might generate the crowding-out effect on other policies. Taking policies PL and VAT as examples, the implementation of VAT can improve the coal industry's profit quickly in the short run due to it reduced the coal industry's cost directly (as shown in Fig 6(b)). Once the profit situation of the enterprises was improved, their innovation impetus would be reduced, and they would use their capital for expanded reproduction. This reversal might upgrade the coal production once again which has been reduced by the implementation of PL. And this demonstrates that the crowding-out effect might be generated by the implementation of PL and VAT at the same time. So, it is necessary to explore the synergy and crowding-out effects of the implementation of the policies. Additionally, in the wake of the economic slowdown, the Chinese government is under pressure to transform economic development, and improve the quality and efficiency of economic growth. So, we discuss the effects on industrial profit from PL, TI, AI, and VAT. Specific calculation methods are shown in the Table 1 (Appendix C).

In Fig. 8(a), the effects of PL-AI, PL-TI and PL-(AI+TI) are all superior to that of PL-SPS, and the effect of PL-(AI+TI) is most significant, which indicates that the simultaneous implementation of PL, AI and TI will generate the synergy effect for PL. Meanwhile, the effects of PL-VAT, PL-(VAT+AI), PL-(VAT+TI) and PL-(VAT+AI+TI) are all inferior to that of PL-SPS, PL-AI, PL-TI and PL-(AI+TI) respectively. Therefore, there might be generated the crowding-out effect for PL by the simultaneous implementation of PL and VAT.

In Fig. 8(b), the effects of TI-AI, TI-PL, TI-(AI+PL) are all superior to that of TI-SPS, which indicates that the simultaneous implementation of TI, AI and PL will generate the synergy effect for TI. And the effects of TI-VAT, TI-(VAT+AI),TI-(VAT+PL) and TI-(VAT+AI+PL) are all inferior to that of TI-SPS, TI-AI, TI-PL and TI-(AI+PL) respectively. Therefore, the simultaneous implementation of TI and VAT might generates the crowding-out effect for TI.

In Fig. 8(c), the effects of AI-TI, AI-PL, AI-(TI+PL) are all superior to that of AI-SPS. So, there might be generated the synergy effect for AI by the simultaneous implementation of TI, AI and PL. It is worth noting that the effects of AI-VAT, AI-(VAT+TI), AI-(VAT+PL) and AI-(VAT+TI+PL) are all weaker than that of AI-SPS, AI-TI, AI-PL and AI-(TI+PL) respectively. Therefore, the simultaneous implementation of AI and VAT might generates the crowding-out effect for AI.

In Fig. 8(d), the effect of VAT-SPS is most significant, which indicates that the simultaneous implementation of VAT and one or couple of other policies will not generate the synergy effect for VAT. And among all scenarios, the effect of VAT-(PL+AI+TI) is the worst. Therefore, the simultaneous implementation of VAT, PL, AI and TI will generate significant crowding-out effects for VAT.

Consequently, the simultaneous implementation of PL, TI and AI can generate the synergy effect for each of them. And the simultaneous implementation of VAT and one or couple of other policies will generate the crowding-out effect both for VAT and other policies. Moreover, the crowding-out effect for VAT will be most significant by the implementation of CP.

Here insert Fig.8. (a), (b), (c), and (d)

5. Conclusions, policy implications, and outlook

5.1. Key conclusions

In this study, we construct a CIDEEM, and demonstrate that the model is trustable to represent Ordos' industrial system's behavior through a dimensional consistency and an authenticity test. Based on scenario analysis, we simulate the changes of industrial production value and profit in coal and oil prices scenarios, as well as policy scenarios.

First, the decreases in coal and oil prices can promote the development of non-resource based industries, but have significantly negative influence on the overall level of regional industry development. Specifically, the effects of the energy price slump on industrial profit are much larger than that on output value.

Second, the effects of each policy on different industries in the coal-chemical industry district have certain differences. In terms of output value and profit for the whole industry, TI and AI have a significantly positive influence. However, these two policies have a certain lag time, and their effect on economic recovery and healthy development of coal mining areas will be revealed gradually over time. VAT reveals results quickly and has excellent short-term effects. Moreover, PL's contribution to industrial profit is much stronger than in the area of industrial output value. Although the implementation of FS can improve the industrial output value, it will weaken the industry profitability.

Lastly, the policies of VAT, TI, PL, and AI have positive effects on the total industrial profit, while FS has negative effects. Moreover, In terms of increasing total industrial profit, the simultaneous implementation of PL, TI and AI can generate the synergy effect for each of them. And the simultaneous implementation of VAT and one or couple of other policies will generate the crowding-out effect both for VAT and other policies.

5.2. Policy implications

In order to reduce the effects of coal and oil price slumps on the economy of the coal-chemical industry district, and to promote the recovery and healthy development of coal mining areas, we recommend a series of policies and measures based on the TI, AI, PL, VAT, and FS scenarios.

TI has great potential. Presently, the effect of TI on economic growth of the energy base in China has not been fully demonstrated. Empirically, the research and development of technologies require a large and stable amount of capital investment, and have a longer payback period. Therefore, the enterprises usually lack the motivation to research such technologies. Moreover, the government needs to lead the enterprises to increase the investment in science and technology by using finance and tax in order to increase their innovation input. Additionally, the government should execute preferential policies for enterprise technology innovation strictly, such as the reduction of national high-tech enterprise income tax, R&D costs reduction, etc.

In the long run, AI plays an important role in increasing industry diversity and reducing economic vulnerability in a mining area. The government should promote the cultivation of alternative industries and optimization of the industrial structure to improve the quality of regional economic performance. For the selection of alternative industries, the government should fully consider intra- and inter-regional comparative advantages in order to avoid reckless and short-term project development (Long, et al., 2013). Meanwhile, the central government should provide the necessary financial support and favorable policies due to the inadequate ability of the mining area to attract external investment, and the local government need to facilitate the construction of infrastructure and improve the investment environment.

PL is an effective way to solve differences in coal and coal-chemical industries' supply and demand. However, through on-spot investigation of more than 30 coal and coal-chemical enterprises in the province of Shaanxi, Inner Mongolia and Shanxi, we find that many firms expand their production continually in order to reduce their unit production cost. Thus, the phenomenon of "limit but not less" and "more limit and more production" occurs in these areas. Therefore, the regional governments should build the scientific capacity assessment system of relevant industries by considering the resource occurrence condition, market demand situation, etc. Meanwhile, the government should clear the standard of backward production capacity, and use the survival of the fittest in market competition to let the inferior enterprises with high costs and high energy consumption be eliminated from the market timely. Moreover, supporting the merger and acquisition of high-quality enterprises over inferior enterprises may be an effective way to diminish overcapacity.

The mechanism design for FS is important. The promotion effect of FS on regional economy development is increasingly significant. However, given the background of the overcapacity of coal and coal-chemical products, more capital input into the production field of coal and coal-chemical products will aggravate the overcapacity situation of these industries and lead the vicious cycle of overcapacity→industry losses→financing→overcapacity intensified→loss surface expansion→refinance, etc. Therefore, the relevant departments should intensify the scrutiny on the credit situation of coal enterprises and the supervision of loan funds use. First, the relevant departments should restrict the credit funds to be used for production expansion of coal and coal-chemical products. Specifically for the "Zombie enterprises," which have poor competitiveness, serious overcapacity, and are unable to stop loss, they should squeeze and exit related loans. For the projects of coal and coal-chemical industry without legal formalities, the relevant departments should not provide any form of new credit extension. Second, the government should support the large coal and coal-chemical enterprises with competitive advantage to guarantee with each other by using good assets, and encourage them to finance by mining right mortgage, issuing corporate bonds, etc. Third, for the enterprises which transfer their capacities to overseas properly, the relevant department should support them to strengthen their cross-border investment and management capacity by overseas loan under domestic guarantee, foreign exchange, etc.

VAT is a rapid way to promote the turnaround of the coal industry. The central government should give full consideration to the characteristics of production and management in the coal industry. They should optimize the structure of taxes and accelerate the improvement of the coal VAT policy, according to the productivity level of the coal industry and the average taxes and fees of industries in China. First, they should lower the standards of tax rates on coal products, reduce the coal VAT rate to 13%, or even to 11%. Second, the scope of coal VAT deduction shall be expanded, and, in view of the particularity of coal mining and the fact that coal VAT is high, they can allow mining rights price, water resources compensation, mine environment treatment deposit, village relocation fee, and compensation for land subsidence to deduct input tax.

5.3. Outlook

In this paper, the main conclusions are based on Ordos' case study. Without considering the industrial structure and level of development of different coal-chemical industry districts. Moreover, the implementation cost of each policy was not considered in this analysis and needs to be studied further.

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