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What factors determine the success and failure of innovation in China?

A systemic study of the Chinese mining industry

Zhenyu Fu

Centre of Development Studies, University of Cambridge

This dissertation is submitted for the degree of

Doctor of Philosophy

Darwin College November 2017

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What factors determine the success and failure of innovation in China?

A systemic study of the Chinese mining industry

Zhenyu Fu

Abstract

China's economy has enjoyed rapid development in recent decades. Its achievements in innovation, however, are far from satisfactory. So why is it the case that innovation has not followed? The mining industry is chosen as the research target. Above all, it is indispensable for China's future energy security and some materials can be used and have no replacement for the manufacture of a constellation of high-tech products. Secondly, mining is a difficult case for the study of innovation. Finally, this study is located at the overlap between development studies and political economy.

This research adopts a qualitative method. Its aim is to find the mechanism through which innovation outcomes can be determined as the qualitative method can be beneficial in presenting such a mechanism clearly. The data is collected mainly through interviews. This research is first illuminated by System of Innovation(SI) theory. SI views concrete innovations as the outcome of a System. This research adopts the Triple Helix approach to organise interviews and conduct fieldwork. This approach focuses upon the

interaction of universities, governments and industries. The Innovation Ecosystem is also utilised to produce systemic research results.

The empirical finding of the research recognises that, compared with the prospecting and manufacturing stages, the mining and mineral processing stages are more innovative. One theoretical finding is that the triple helix displays in different forms under different circumstances.

More work ought to be done to further discern and update the evolution of a Chinese National System of Innovation and a comparison of the different forms of Triple Helix is also a rich vein for scholars.

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Abbreviation List

NSI：National System of Innovation

SI：System of Innovation

RSI：Regional System of Innovation

SSI：Sectoral System of Innovation

TH：The Triple Helix

APRA：The Advanced Projects Research Agency

DNS：Developmental Network State

MDRC：Municipal Development and Reform Commission

CCP：Chinese Communist Party

BIIT：Bureau of Industry and Information Technology

BOF：The Bureau of Finance

BOST：The Bureau of Science and Technology

MGO：The Municipal Government Office

CAS:Chinese Academy of Science

SASAC:State-owned Assets Supervision and Administration Commission

TM:Tiandi-Marco

GLF:The Great Leap Forward Movement

Abstract

China's economy has enjoyed rapid development in recent decades. Its achievements in innovation, however, are far from satisfactory. So why is it the case that innovation has not followed? The mining industry is chosen as the research target. Above all, it is indispensable for China's future energy security and some materials can be used and have no replacement for the manufacture of a constellation of high-tech products. Secondly, mining is a difficult case for the study of innovation. Finally, this study is located at the overlap between development studies and political economy.

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1. Research Question

China's economy has enjoyed a high rate of development in recent decades, enabling it to become the second largest economic entity in terms of GDP in the world. Its achievements in innovation, however, are far from satisfactory. Meanwhile, China is not home to a group of globally competitive firms (Nolan, 2004).This phenomenon becomes all the striking if we take the following figures into account: the speed of growth regarding R&D investment is faster than GDP growth; over the last 10 years, the Beijing government has dramatically increased expenditure on R&D, which has risen from 0.6% to 1.6% of GDP from 1999 to 2011 (Hannas et al., 2013, p.53),and this figure rose to 2% in 2013 (Boeing et al, 2016, p.159), and China also produces a large number of researchers to staff these research units, ranking second in the world after the United States and ahead of Japan in the number of researchers over the past decade (OECD, 2008). In addition, from roughly 2006 onward, "Indigenous Innovation" has become one of the slogans of the Chinese government, being popular and often mentioned by officials at different levels. The outcome of this movement, however, is not desirable. Most of the R&D labs established over the past decade belong to multinational firms, not Chinese firms (Hannas et al.,2013). Hannas et al (2013, p.56) point out that the R&D intensity of high-tech industry in China remains much lower than that of developed countries. In 2008, China's high-tech industry only invested 1.15% of its revenue to R&D. This was much lower than the 2006 ratio for the US (16.41%), the UK (11.01%), Japan (10.64%), Germany (8.34%), and the Republic of Korea (5.98%). Not only has China failed to enhance innovations rapidly but the innovation activities being implemented in China lack an indigenous dimension. So why is it the case that innovation has not followed? It is of great significance for China. As is widely known, China is going through a transitional period and its aim is to transform a labour-intensive economy into a capital-intensive economy, and finally into a knowledge-intensive economy. Whether China can realise this goal or not hinges on whether the country can address the underlying problem which impedes the promotion of Chinese industry and undermines the pursuit of innovation. In fact, China is trying hard to bolster its companies' investment in R&D. According to the 2016 EU Industrial R&D Investment Scoreboard: 'As in the past few years, companies based in China continued to show the best performance in terms of R&D growth (up by 24.7%)' (European Union, 2016, p8). Among the 2,500 companies being calculated, there are 327 Chinese companies, and China is ranked third, only beaten by America and Japan. The following table reveals figures for the top 10 Chinese companies on this scoreboard.

World rank	Name	Industrial sector	R&D 15/16 (€million)	R&D 1 year growth (%)	(CAGR-3y, %)
8	HUAWEI INVESTEMENT & HOLDING CO.	Technology Hardware & Equipment	8,357.9	46.1	26.3
65	ZTE	Technology Hardware & Equipment	1,954.1	34.1	12.4
79	PETROCHINA	Oil & Gas Producers	1,677.6	-9.4	-6.4
91	CHINA RAILWAY	Construction & Materials	1,454.7	5.9	17.0
93	BAIDU	Software & Computer Services	1,444.5	46.2	63.3
96	CRRC CHINA	Industrial Engineering	1,407.9	92.0	48.0
106	LENOVO	Technology Hardware & Equipment	1,284.7	20.2	31.3
111	CHINA RAILWAY CONSTRUCTION.	Construction & Materials	1,239.4	0.9	10.0
116	SAIC MOTOR	Automobiles & Parts	1,184.5	22.5	13.3
117	TENCENT	Software & Computer	1,177.4	19.9	25.8

Services

Table1: Top 10 Chinese companies on The EU Industrial R&D Investment Scoreboard 2016

Source: http://iri.jrc.ec.europa.eu/documents/10180/1030082/World 2500 companies ranked by RD.

Based on the foregoing, why has China been unable to improve its companies' innovativeness, despite investing a large sum of money in R&D institutions and employing an increasing number of R&D personnel?

Year	Total	Basic Research	Applied Research	Experimental Development	% of GDP
2011	868.7	41.2	102.8	724.7	1.78
2012	1029.8	49.9	116.2	863.8	1.91
2013	1184.7	55.5	126.9	1002.3	1.99
2014	1301.6	61.4	139.9	1100.4	2.02
2015	1417.0	71.6	152.9	1192.5	2.07

Table2: China’s Intramural Expenditure on R&D Units by billion yuan (during this period one dollar approximately equalled 6.3 yuan)

Source: China Statistical Yearbook on Science and Technology, 2016.

Item	2006-2011	2007-2012	2008-2013	2009-2014	2010-2015
Percentage	51.7	52.2	53.1	54.2	55.3

Table3: The contribution of the advancement of S&T to China’s Economic Growth

Source: Ibid.

This question is rather important and timely for China. After enjoying around a decade’s economic growth at a staggering speed, China's Gross Domestic Product growth rate has slowed down, especially in the past two years to a rate of lower than

7%, although still very high compared with other countries. It is time for China to find a new way to boost its economy again. The reform and opening-up policy has turned China into an export-oriented economy. This trend, however, needs to be reversed to some extent if China wishes to build its economy on a more concrete foundation. Not long after the outbreak of the 2008 financial crisis, domestic-need stimulation policy won the support of both the populace and the officials. The outward economy depends upon whether the commodity-receivers' economy is prosperous or not, thereby always relying upon other countries. If a large proportion of the economy is closely linked with exports, this economy shares the fate of the world economy and is vulnerable to downturns in major economies. As a consequence, reducing the reliance of the Chinese economy upon exports and increasing the percentage of domestic consumption is considered as a prescription. The question is how to make domestic consumers purchase Chinese products, which are often regarded as low quality and have shoddy after-sale service. To resolve this issue, innovation is an unavoidable topic. Only by encouraging Chinese firms to engage in indigenous innovation and attach more importance to in-house R&D can these companies salvage their images and attract more consumers. Responses to this issue will largely determine the development trajectory of China in the first half of the 21st century. At this stage, China is still a technology follower. There are various ways to do: "By learning from the best and focusing innovation efforts on design and cultural change, firms from the unlikeliest places can catch up and then move ahead of world leaders"(Forbes & Wield,2002). Chinese firms can draw upon the experiences of other countries. But no matter which method they choose to use, innovation is a prerequisite.

Before probing deeper, I would like to clarify one fundamental concept, e.g. innovation. This concept had its own colloquial meaning many centuries ago, but the person who saw its academic significance and made the greatest contribution to a new discipline is Joseph Schumpeter. In his masterpiece *Business Cycles,* Schumpeter:

> simply defines innovation as the setting up of a new production function. This covers the

> case of a new commodity, as well as those of a new form of organisation such as a merger, of the opening up of new markets, and so on (Schumpeter, 1939, p.87).

He also mentions that:" innovations entail construction of new plant, embodied in a new firm and are always associated with the rise to leadership of new men" (Schumpeter, 1939, p.93-96). Countless scholars have made their contribution to this important academic stream, but different researchers have different understandings of innovation. Nelson defines innovation rather broadly, referring to the: "process by which firms master and get into practice product designs and manufacturing processes that are new to them if not to the universe or even to the nation" (eds Nelson, 1993). Meanwhile, Edquist defines innovation simply as: "new creations of economic significance" (1997). These definitions overlap to some extent and by using different criteria we have different typologies. As a result, I need to make it clear at the beginning of my research what innovations I study. I use the concept of innovation to refer to the commercialisation of new ideas or new designs, including the adoption and creation of innovation, and I mainly discuss technological innovation. In the meantime, I give more credit to “Indigenous Innovation”. The landmark document which officially announced the campaign of encouraging indigenous innovation is “The National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020)” (now known in the West as the MLP). It defines indigenous innovation as: “enhancing original innovation through co-innovation and re-innovation based on the assimilation of imported technologies” (quoted in McGregor, 2010, p4). According to Lu:

> Indigenous innovation here refers to a kind of strategic principle or policy adopted by a firm or a state. Under the guidance of the philosophy of indigenous innovation, the firm or the state will insist on technology learning and treat the ability to develop technology as the main source of competence or the motivation of economic development. (Lu, 2006, p.36).

Zhou and Liu (2016, p.46) argue that: “the ‘indigenous’ translation is somewhat misleading, as indigenous in Chinese is 自主, which literally means self-directing, and does not necessarily describe technology that has to originate in China or be free of foreign contribution”. I agree with Zhou and Liu. In this research, the term “indigenous innovation” will be retained as it is quite popular, but it needs to be stressed that Zhou and Liu’s clarification is useful in helping western readers understand the true significance of this term.

I also wish to distinguish science and technology because these terms are often used together but most people fail to notice the essential difference between them. Mokyr discusses two kinds of knowledge:

> one is the knowledge that catalogues natural phenomena and regularities (‘knowledge of what’), which I will call propositional knowledge. The other is the knowledge that prescribes certain actions that constitute the manipulation of natural phenomena for human material needs (‘production’) and which I will call prescriptive knowledge (2002, p.4).

In fact, propositional knowledge is science, knowledge about interpreting the world, while prescriptive knowledge is technology, knowledge about changing the world. Faulkner proposes a common understanding that: "science is about understanding nature through the production of knowledge and technology is about controlling nature through the production of artefacts". (1994, p.431). In short, science and technology are interlinked but have different functions.

As far as development studies is concerned, innovation is the essential part of every successful development story. When Alexander Gerschenkron first proposed late development studies (Gerschenkron,1962), capital accumulation was the main task for developing countries who pursued industrialisation and innovation was ignored. Scholars of that era did not care too much about innovation as if innovation is a concomitant of industrialisation. As time went by, the function and value of innovation was gradually recognised by most, if not all, scholars. A country unable to contribute with a world-famous brand will not be respected, even though its aggregate economic figure is significant. Since Schumpeter's masterpiece first related that the significance of innovation is creative destruction (Schumpeter,1942), this phenomenon has attracted huge attention from a variety of disciplines. Numerous schools of innovation have been established. Although the discourse of innovation is inclusive, developing countries are by no means the prime concern of this academic stream. My research is relevant to innovation studies and development studies. I hope to bridge the two and bring development studies into the core research domain of innovation.

The diversity and knowledge-intensity of the world economy has grown exponentially in recent years. As the engine of economic growth innovation has been acknowledged globally, and the emerging economies will not sustain their development unless they participate in innovation-creation or diffusion activities wholeheartedly. It is predicted that innovation will penetrate into every sphere of the economy and serve as one of the main criteria to evaluate the performance of a specific economic entity, be it a firm or a country.

China's economic miracle is unparalleled whereas it will be less shining if we take its innovation performance into consideration. China's case provides a great many opportunities to researchers. Academic studies of China should be a rewarding process as they not only benefit scholars involved but also offer an excellent testbed for a wide range of competing theories. Moreover, by helping China to tackle the problems facing it, the whole world will benefit.

In the academic community, innovation is generally considered to be the outcome of a number of players. In consequence, the whole system which leads to the creation and adoption of innovation will be looked at rather than focusing upon one node in a larger network. Only by giving innovation its due credit in society can its function be correctly exposed. After all, it is the interaction between innovation and social development that matters. The significance of innovation lies in its integrating role, linking different parts of society and binding them together, thereby accelerating the production of useful knowledge. Based on the foregoing, a systemic approach will be adopted in this research.

In order to narrow down the scope of my research, the mining industry is chosen as the research field. According to the broadest definition, mining includes discovering, extracting, and processing of all non-renewable resources up to the point at which they are used as inputs for fabricating or producing energy. A much narrower definition of mining includes only crude or non-processed mine products such as mineral ores and coal, and excludes petroleum and natural gas (Mikesell & Whitney, 1987). This research mainly looks at specific mining industry. Coal mining, non-ferrous metal mining, and mining equipment manufacturing were selected in order to focus this research.

The reasons why the mining industry was chosen is because it has the following features:

Above all, it is a strategic industry as it is indispensable for China's future energy security and some materials are indispensable to a constellation of high-tech products. The coal mining sector alone is quite important, although it is not the mainstay of Chinese industry any longer. In the mid-1990s China became the largest producer of coal in the world (Thompson, 2003). Now coal consumption provides nearly 70% of the total energy needed by the country. In 1978 the mining and quarrying industry had 6.52 million workers. Then with reform and opening-up, this figure increased significantly. In both 1993 and 1995, the mining industry employed 9.32 million workers, an all-time high. This figure slowly fell. In 2014, among 182.78 million urban workers, 5.97 million worked in coal mining, ranked the eighth largest industry, and exceeded by manufacturing, construction, education, public administration and so on (National Bureau of Statistics of China, 2015).

Unit 10,000 persons	Total	Mining	Manufacturing	Construction

2012	15236.4	631.0	4262.2	2010.3
2013	18108.4	636.5	5257.9	2921.9
2014	18277.8	596.5	5243.1	2921.2

Table4: Urban Units Employment by Sector

Source: China Labour Statistic Yearbook, 2015.

Negative factors have also attracted attention, such as the notorious accidents which claimed hundreds of people's lives. As for the non-ferrous metal industry, in 2014 ten kinds of non-ferrous metal (copper、aluminium、nickel、lead、zinc、tungsten、molybdenum、tin、antimony and mercury) reached a production quantity of 48.11 million tons, 7.1% higher than in 2013. The same year, investment in the fixed assets of the non-ferrous metal industry was 695 billion yuan (US$113.2 billion),4.4 % higher than 2013. State-owned and large non-state industrial enterprises in the non-ferrous metal industry enjoyed a revenue of 5.29 trillion yuan (US$861.6 billion), 8.3% higher than 2013 (The Yearbook of the Chinese Non-Ferrous Metal Industry, 2015).

Second, the mining industry poses problems for innovation study. When scholars look at China's innovations, the industries they focus upon are information and communication technology or the aircraft industry, few looking at mining. By demonstrating the pivotal role innovation can play in promoting the Chinese mining industry, the importance of innovation can be understood to provide a credible backdrop. The outcome of this research might be an extension of innovation studies and contribute to a finer appreciation of innovation. Meanwhile, to a large extent, most theories and analytic framework of innovation were developed based on the laws of manufacturing. Thus, a study of the mining industry has the potential to articulate novel ideas.

Lastly, this study is located where development studies and political economy overlap. The former's key theme is capital accumulation, while the latter's is the interactions between political factors and economic sectors. The mining industry counts upon huge capital investment and is always under strict government regulation in China. The extraction of primary resources can be an important source of capital for developing countries, and during this capital accumulation process the government's behaviour is critical. The mining industry is salient insofar as it integrates the logic of the two academic branches.

In addition, mining equipment manufacturing is chosen as a large proportion of the innovations in the mining industry are generated by equipment makers. Meanwhile, mining companies themselves are mainly responsible for the commercialisation of new mining or processing methods rather than mining equipment. Only by taking equipment companies into account can this research cover most innovations in relation to mining.

In short, this study looks at innovation in the Chinese mining industry via a systemic approach and tries to answer the question: What factors determine the success and failure of innovation in the Chinese mining industry? It is expected that these factors are also useful to explain the innovation performance of other Chinese industries, as these industries constitute elements of a National System of Innovation.

2. Literature Review

The central role of firms in the creation and diffusion of innovation has been recognised by almost all scholars in the field. No firm, however, can finish the task of innovation by itself. Firm acts as the striker in a football match, as it were, who gives the final kick but without assistance from his teammates, it would be difficult, if not impossible, for the striker to score. Various kinds of organisation take part in the innovation process and, together with firms, they constitute a system. In order to comprehend the real innovation process, it is imperative to look at the whole system. From the 1990s onwards, a theoretical approach called the National System of Innovation has been widely adopted by the academic community and policy-makers. This research is also informed by this approach.[1] Meanwhile, shortly after the birth of the National System of Innovation, similar approaches were proposed, such as Regional System of Innovation and Sectoral System of Innovation. This System of Innovation school will be introduced first, and its strengths and weaknesses discussed.The 21st century has seen the rise of two competing theories, i.e. Triple Helix and Innovation Ecosystem. Both of these theories' supporters agree with the systemic feature of innovation whereas they also have differing views regarding some issues. The Triple Helix theory will be reviewed after the System of Innovation theory,

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[1] Prior to talking about innovation systems, I will throw some light on a similar term, 'Technological System'. This concept was developed by Carlsson and Stankiewicz (1991). They define the Technological System as: "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (1991, p.93). This Technological System is a sub-system of the National System of Innovation. Whilst it is widely accepted that innovation takes several forms, such as the creation of new markets, new products, and new organisations, all of the above-mentioned forms have technological ingredients. Furthermore, essential as technological innovation is, it is definitely not the whole of innovation. In some aspects, however, this technological system has a larger scope than the National System of Innovation, as some technology is transnational or even global. What I wish to stress here is that this concept is no different in nature from NSI but varies in the facet they attach most importance to. The prime concern of this research is technological innovation so this concept would be very relevant to the research too. In debt to Carlsson and Stankiewicz, this research can be redubbed a study for the System of Technological Innovation of the Chinese mining industry.

as it will guide this research. The selection of cases and potential interviewees were decided in the light of this approach, while the conclusion of this research takes note of some lessons drawn from this approach. In this section, one case will be presented, that of Huawei. Huawei is the most successful Chinese company in terms of innovation. An introduction to Innovation Ecosystem follows. Finally, research into the mining industry, especially the Chinese mining industry, will be reviewed.

2.1 System of Innovation

2.1.1 National System of Innovation (NSI)

According to Christopher Freeman (1995, p.5), the first to use the term 'National System of Innovation' was Lundvall. However, in published form, the term was first used by Freeman himself in the book *Technology Policy and Economic Performance, Lessons from Japan* (Freeman, 1987). As a result, the academic community credits Freeman with coining this expression. In fact, the concept goes back to Friedrich List (1984) who at the time, was thinking about the method Germany might use to overtake Britain. He was in favour of infant industry protection policy, a major part of which was about learning new technology and applying it.

In the 1990s, there were two influential monographs concerning the National System of Innovation, one is *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, edited by Bengt-Åke Lundvall (1992), and the second is *National Innovation Systems: A Comparative Analysis*, edited by Richard Nelson (1993). In 2008 the book *Small Country Innovation Systems, Globalization, Change and Policy in Asia and Europe,* edited by Charles Edquist, provides the latest approach to studying NSI. The three books articulate different perceptions of the same term, but they do not contrast with each other. In fact, they complement each other in one way or another.

As for the National System of Innovation literature, first of all, regarding Freeman's ground-breaking study of this area, it may be argued that it is more of a case study about Japan, the country which, at the time the book was published, was still the world technology leader. Freeman defined the National System of Innovation as" the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (1987, p.1). His study concerns some features of a Japanese System of Innovation and its implications for other countries. Freeman describes the four most important features of Japanese NSI, including the role of the Ministry of International Trade and Industry, the role of company R&D strategy in relation to imported technology and 'reverse engineering', the role of education and training and related social innovation, and the conglomerate structure of industry (1987, p.4). In short, Freeman's methodology identifies major actors in this system and studies them respectively. Its advantages lie in its comprehensive depiction of the system and systematic framework-building. Compared with previous theories, it put innovations in a wider purview, thus contributing to a better understanding of innovation. By paying attention to the innovation network, the nature of innovation can be demonstrated more clearly.

Freeman also discusses changes in industrial leadership throughout history, leading to the conclusion that a nation cannot become a world technology hegemon or overtake the current technology pioneer unless its NSI efficiency or performance surpass that of the current leader. Just as:

> when Britain opened up a major technological gap in the first industrial revolution, this was related not simply to an increase in invention and scientific activities, important though these undoubtedly were, but to novel ways of organising production, investment and marketing and novel ways of combining invention with entrepreneurship. Similarly, when Germany and the US overtook Britain in the late nineteenth and early twentieth centuries their successes were also related to major institutional changes in the NSIs. In particular, they developed new ways of organising R&D activities as specialised departments within firms, and employed graduate engineers and scientists (Freeman, 1987, p.31).

This idea is very illuminating. Previous studies merely emphasized one specific sector of the economy, thus failed to explain the leapfrog of late developers. If a country intends to outperform its competitors, this country's NSI overall performance should excel. From the very beginning of the study of NSI, this has had policy implications. Government policy plays a pivotal role in shaping a country's NSI and many countries have experienced this. This policy implication offers new rationales and new approaches for government technology policies (OECD, 1997). To sum up, as the first attempt to use NSI to approach innovation, whilst very rudimentary, Freeman's book was a pioneer. Almost all later studies in this area make reference to it.

Lundvall's is a more theoretical study. It first makes a distinction between a System of Innovation in the narrow sense and a System of Innovation in the broad sense. The narrow definition includes "organisations and institutions involved in searching and exploring" (1992, p.12), while the broad definition "includes all parts and economic structure and the institutional set-up affecting learning as well as searching and exploring" (1992, p.12). The core concepts in this book are knowledge and learning; Lundvall argues that:

> the most fundamental resource in the modern economy is knowledge and accordingly, that the most important process is learning…it is assumed that learning is predominantly an interactive and therefore, a socially embedded process which cannot be understood without taking into consideration its institutional and cultural context (Lundvall, 1992, p.1).

The outcome of innovation is new knowledge, not new products or new methods of production, and the process of making innovation is learning. This perception is very accurate. It points out that products are carriers of knowledge, in other words, the materialisation of knowledge. Viewed from this perspective, the main activity in an NSI is collective learning. All parts of the system should contribute to the accumulation of useful knowledge, otherwise it should be excluded from the system. The most effective systems of innovation are those which create the largest amount of knowledge. This interpretation of NSI is also helpful in the sense that it gives researchers a conceptual tool to evaluate each NSI. Furthermore, Lundvall stresses that the process of learning is interactive and innovation is gradual and cumulative. Thus, he mentions that learning takes place in connexion with routine activities. He points out the possibility that even workers and sales representatives influence the agenda, determining the direction of innovative efforts, and that in this way the learning base is enlarged.

Lundvall's book provides a theoretical groundwork for incoming NSI studies, and exposes the nature of innovation. Although lacking empirical evidence, the theoretical coherence of the book holds every chapter together. Furthermore, the inclusive style of the book is beneficial for delineating a panorama of innovation. While which part of the picture is more relevant in specific cases, it cannot be predetermined. “A problematic aspect of learning organisations as well as the learning economy in general has been its focus on catching up learning base on incremental innovations and not on radical innovations requiring the creation of new knowledge” (Asheim & Coenen, 2005, p.1175). Learning is about diffusing innovation throughout the economy. In the short term, it might be very efficient in adopting innovation but in the long term it is difficult for the learning economy to abandon this development pattern.

Nelson's and Lundvall's book differ in many ways. Nelson’s consists of 15 case studies ranging from large high-income countries such as the US, Japan, and the UK to low-income countries, i.e. South Korea, Brazil, and Argentina. It is much more empirical than Lundvall’s. In the first chapter, Nelson gives his definition of
‘innovation’, ‘systems’, and ‘national’. The system concept, according to Nelson, is: "that of a set of institutional actors that, together, plays the major role in influencing innovative performance” (eds Nelson, 1993). No matter which country is discussed, the authors are mainly concerned with formal actors. In other words, it is the formal institutions that catch the attention of the contributors, unlike Lundvall's work. By

talking about the 'major institutional actors', the book mainly discusses firms, industrial research laboratories, universities, and public laboratories. Each chapter only sheds light to the important formal institutional actors.

There are some other valuable lessons and striking features of NSI which are demonstrated by Nelson. First of all, history matters. It does not ignore the outside world, it is an open system. As described, the international environment and the time of industrialisation influence the structure of NSI. Even though we are talking about NSI, it does not mean we can ignore the international context. Most countries whose governments invest heavily in the R&D sector probably do so because these countries face severe military threats. As the national defence industry is different from civilian industry, the commodities of this industry cannot be brought to market, thus government intervention is in high demand. Apart from this, the size of the economy and its geographical location also have important impacts on the country's NSI, especially during its formation process. As Nelson lucidly depicts, most smaller economies have similar features, reminding us that a vision cannot be formed without noticing real world constraints. Furthermore, variation in size and location is hard to change so that some experiences are unique to one country or its counterpart, while other countries cannot simply copy these successful models. In other words, best practice does not exist. All in all, this book uses plenty of case studies and comparisons to show the similarities and differences between NSIs. It laid the foundation for future progress.

As for Edquist, his book is quite different from the two above. Edquist classifies Nelson’s and Lundvall's way of studying NSI as traditional approaches (Edquist, 2008). The approach Edquist adopts is called 'An Activities-based Framework for Analysing SI’. To be more specific, “the main or overall function of SI is to pursue innovation processes: to develop and diffuse innovation” (Edquist, 2008, p.7). Activities here refer to those factors that influence the development and diffusion of innovations. Compared with Nelson's and Lundvall's work, Edquist: "focuses strongly on what happens in the systems—rather than on their constituents[2]—that it thus uses a more dynamic perspective" (Edquist, 2008, p.7). Traditional approaches focus strongly upon components within the system. Because it is extremely difficult to distinguish which activities are linked with innovations, Edquist adopts ten activities. They are divided into four categories: Provision of knowledge inputs to the innovation process, including provision of R&D and competence building; Demand-side activities, including formation of new product markets and articulation of quality requirements; Provision of constituents of SI, including creating and changing organisations needed for developing new fields of innovation, networking through markets and other mechanisms, creating and changing institutions, and Support services for innovating firms, including Incubation activities, financing of innovation and provision of consultancy services. This perspective helps readers understand the function of different components of an NSI better because it deals with actors in motion not static actors. Even different NSIs have the same components, while these components might not serve their functions the same way. Sometimes a component is designed to perform a specific task but in reality, it often deviates from its basic task and takes on other responsibilities. Only by observing and analysing acting components can we gain meaningful knowledge of these components. Meanwhile, activity-based studies are more conducive to show the interactions between constituents of the system, which are as important as the constituents themselves, if not more important. The so-called traditional manner of NSI study approaches are weak in this respect. However, by concentrating on activities of the system this approach is not strong in introducing each component clearly. If, for example, some components engage in less activities there will have less chance that they appear. The significance of these components, however, is not necessarily less noticeable than others.

[2] The constituents and the components of a System of Innovation refer to the formal institutions and organisations of this system, such as firms, universities, banks, governments, and legislative systems.

Based on the foregoing, it can be seen that the two kinds of approaches have their own strengths and weaknesses, which make them complement each other.[3]

Some concluding remarks needed to be made here. Initially, some of the features of this framework which capture the essential rules of innovation are worth noting. Above all, it reminds scholars that innovation is by no means a completely technological phenomenon. You cannot grasp the essence of innovation until you place it into a larger socio-economic picture. In his book *Forces of Production, A Social History of Industrial Automation,* Noble clearly and eloquently states his point of view:

> Technology determinism, the view that machines make history rather than people, is not correct; it is only a cryptic, mystifying, escapist, and pacifying explanation of a reality perhaps too forbidding (and familiar) to confront directly. If the social changes now upon us seem necessary, it is because they follow not from any disembodied technological logic but from a social logic-to which we all conform (Noble,1986, p.324).

Noble uses one case study to illustrate the decisive power of social rules in solving a seemingly technological problem. Among the two competing machine tools, the one with lower quality won the day. The reason is that, by adopting the lower quality model, the managers could continue to control the production process. The law that guides the advancement of technology is not a technological one, for the same reason that the law that guides scientific discoveries is not a scientific one. In addition, Lazonick compares shop floor relations between workers and employers in Britain, the USA, and Japan (1990). He argues that in Britain, senior workers control the production process; in America, professional managers decide what goes on at

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[3] Along with the national System of Innovation, another concept is worthy of mention, that is, the National System of Entrepreneurship. It is a: "fundamental resource allocation system that is driven by individual-level opportunity pursuit. In contrast with the institutional emphasis of the National Systems of Innovation frameworks, where institutions engender and regulate action, National Systems of Entrepreneurship are driven by individuals, with institutions regulating who acts and the outcomes of individual action" (Ácsa et al.,2014). National Systems of Entrepreneurship focus upon different aspects of innovation and I will regard them as a complementary approach to NSI.

the assembly line; while in Japan, the shop floor workers are integrated into the planning of production. The vicissitudes of the three countries in world industry can be explained by this relationship (Lazonick,1990). Both Noble and Lazonick attempt to link technological innovation with human activities. Technology is a means, not an end. Broers' view, expressed in his book *The Triumph of Technology*,is highly doubted here. Broers said "Technology, I repeat, will determine the future of human race…My fervent belief is that technology holds the key to sustaining our banishment of these ills, everywhere and for ever"(Broers, 2005). The NSI approach is beneficial in helping people bear in mind that innovation is created by mankind and thus succumbs to human rules. The NSI approach does not pre-exclude any kind of human activities. The forces that push innovation forward are joint forces of social, political, economic as well as cultural forces. A single-minded focus upon agencies directly engaged in technological activities will definitely miss overriding forces.

Second, this research framework helps form a panorama of innovation, its wide scope is conducive to address the researchers that innovations are possible everywhere. Innovation is the outcome of a network, not the finishing point of a straight line. It is not only about R&D and will not only be produced by R&D; it means much more than that. Pavitt asserts in his article that some small firms' innovative activities and some private sector firms have made contributions to the development of software technology (Pavitt,1999). Innovation is created and diffused in the system in various ways. The formal R&D sector only occupies a small portion of this. The R&D sector cannot monopolise that comes from innovation. This approach is also a forceful refusal of the linear innovation model. In Stokes' book he described this model as: "Basic research→applied research→development→production and operation". (Stokes, 1997, p.10). A System of Innovation consists of numerous such lines, along with lines of different sorts, and none are one-way streets. Feedback from both sides of the line can be a source of innovation. It confirms the idea that different components of the system all have their unique functions and contributions. Stokes uses a categorisation to distinguish three kinds of research, that is, pure basic research, pure applied research, and use-inspired basic research, arguing that use-inspired basic research yield most economic significance and economic returns for investors (Stokes, 1997). More often than not, research interests aroused by practical concerns could lead to the establishment of a new discipline. This model is reconciled with NSI. Technology and science cannot determine the trajectory of innovation. The system's input is not only wrought in scientific breakthroughs but teems with problems in real life. All kinds of input can be transferred to the output, e.g. innovation.

Finally, this approach is quite inclusive and multidisciplinary. As Pavitt points out in his book: "the blind spot of many economics in ignoring what goes on inside innovating firms is often matched by the blind point of many management specialists in ignoring what goes outside" (Pavitt,1999). While NSI helps both groups reduce, if not remove, their blind section it always set the whole economy as the backdrop and will not gratuitously exclude any part. By adding more elements in the system, the framework opens doors to scholars from a wide range of subjects.

While I am going through NSI literature, I always encounter complaints which claim that the 'national' background has become obsoleted in a globalising world. Some scholars propose an open innovation approach. They argue that: "firms which do not co-operate and which do not exchange knowledge reduce their knowledge base on a long-term basis and lose the ability to enter into exchange relations with other firms and organisations" (Koschatzky, 2001, p.6). Meanwhile, others argue that national differences still matter. Pavitt and Patel measure the uneven (divergent) technological accumulation among advanced countries (Pavitt & Patel, 1998), finding that technological abilities among developed countries are far from following a convergent process. This can be explained in local inducement mechanisms, the volume and rate of increase of aggregate innovative activities by differences in systems of corporate governance, and in the level and composition of workforce education. All these are still quite local. Every book on NSI allocates one sub-chapter to the 'national'. Lundvall argues that innovation entails complex communication between different parts. The exchange usually has a tacit or uncodified part, parties from the same national environment will facilitate the discourse (Lundvall, 1992). Freeman defines a System of Innovation at different levels in his article *Continental, national, and Sub-national innovation systems-complementarity and economic growth*. He believes that: "the major phenomena of forging ahead, catch up and falling behind in the 19th and 20th centuries can most plausibly be explained in terms of national systems albeit in an international context and recognising uneven development at the sub-national level" (Freeman, 2002, p.209). Apart from innovation studies, Variety of Capitalism theory offers more intellectual evidence of the important national dimension (Hall & Soskice, 2001). Liberal market economy (LME) and coordinated market economy (CME) use different mechanisms to deal with problems in their own economies. In a globalising world, they might copy some so-called best practice from countries of the other category, but this is only individual policy learning and will not change the fundamental principles of the economy. The opposite trend is also obvious, as some speak highly of prominent regional systems of innovation, such as Silicon Valley. These science parks organise innovative activities in a much more efficient way than the institutional set-up at the national level.

Meanwhile, some scholars propose the idea that sectoral features are more important than the geographical or political dimensions. Different sectors have quite different features so it might be more possible for the same sectors in different countries to strike a chord than different sectors in the same country.

Based on the foregoing, it is necessary to review the literatures on the regional System of Innovation and the sectoral System of Innovation.

2.1.2 The Regional System of Innovation

This academic stream goes back to Alfred Marshall's *Principle of Economics* (1922) in which he discusses the development and features of industrial districts, or as the author calls the phenomenon "the concentration of specialised industries in particular localities". Most contributors to this field share the underlying idea that territorial agglomeration provides the best context for an innovation-based globalising economy owing to localised interactive learning processes and sticky knowledge grounded in social interactions (Allura, Galvagno & Li Destri, 2012). The stickiness of knowledge is an important concept here. It was developed by von Hippel (1994), who discusses the relationship of sticky information and problem-solving: "Often the information used in technical problem solving is costly to acquire, transfer and use in a new location" (1994, p.429). If most of the innovative activities concentrate on one region, the problems caused by [sticky information] will be less severe. The barriers that need to be removed in the process would require less labour, and technicians do not bother to move rapidly from one place to another in order to detect the problem. At least in theory, the existence of a Regional System of Innovation (RSI) is possible.

When NSI, RSI are compared: "a key question concerns the extent to which they are indeed 'systemic'" (Cooke et al, 1997, p.478). At least when reviewed by Edquist (1997), the NSI approach is being used more on operational systems. This approach is more likely to attend to what is being done in the system: "this then give rise to a serious problem of what, indeed, an innovation system actually is" (Cooke et al, 1997, p.478). A National Innovation System might include something purposely designed and something not. The question becomes: “Are they going to be involved in an intra-system conflict? Because of the massive complexity of research this at national level, we think there are justifications both for beginning the study of systems with a conceptual rather than operational emphasis and also doing this at regional level in the first glance" (Ibid, 479). The above discussions are theoretical. Whether the NSI or RSI approach is chosen depends upon the characteristics of the targeted area. If this area has strong local features, such as its own educational and training systems, public procurement by the regional government, universities, and research laboratories related to this region, RSI might be a more effective approach. Sometimes national initiatives in large countries do not work as well as in small countries (Cooke et al., 1997). Consequently, RSI is a better choice to study them. Scholars have tried to open the black box of region, and distinguish two kinds of RSI according to their knowledge bases. Asheim and Coenen use the terms 'analytical' and 'synthetic' knowledge base to categorize RSIs. In its philosophical meaning, 'analytical' refers to the way of reasoning by which the truth of a proposition independent of fact or experience involves inference from a general principle. 'Synthetic', on the other hand, pertains to knowledge having a truth value determined by observation or facts (2005, p.1176). In RSI where the knowledge base is analytical, science is important and knowledge creation is often based on cognitive and rational processes. Whereas in RSI, where the knowledge base is synthetic, innovation takes place through the application of existing knowledge or new combinations of knowledge. Asheim and Coenen argue that: "in case the following two subsystems of actors are systematically engaged in interactive learning, it can be argued that a regional innovation system is in place.(1)The regional production structure or knowledge exploitation subsystem which consists mainly of firms, often displaying clustering tendencies.(2)The regional supportive infrastructure or knowledge generation subsystem which consists of public private research laboratories, universities, etc" (Asheim & Coenen, 2005,p.1177).

All these theories are quite useful when researchers are contemplating whether there is an RSI in a specific region and choosing which aspects to stress.

Apart from those theoretical building works, several case studies are also worth mentioning. Saxenian studies the performance divergence between Silicon Valley and Route 128 which are world renowned high-tech regions (Saxenian,1996). Her explanation is a typical RSI one:

> Silicon Valley has a regional network-based industrial system that promotes collective learning and flexible adjustments among specialist produce] a complex of related

> technologies. The Route 128, in contrast, is dominated by a small number of relatively integrated corporations. Its industrial system is based on independent firms that internalize a wide range of productive activities. It reinforces a regional culture that encourages stability and self-reliance (1996, p.3.).

Kirk and Cotton's recently published book *The Cambridge Phenomenon,50 years of Innovation and Enterprise* is also a typical RSI study although they do not use this term explicitly (Kirk & Cotton, 2012). They depict the thriving business and academic community in Cambridge, consciously describing the interaction between the University of Cambridge and the science parks around the university. They eloquently point out that: "no cluster is an island." They then analyse the function of different components of this small RSI. They conclude that 'Cambridge spirit' is a particular feature of the overall culture in this place, an attitude of willingly helping others without expecting anything in return which cannot be found anywhere else (Kirk & Cotton, 2012, p.200). Maybe this is because, in its embryonic stage, the environment in Cambridge was hostile to setting-up in business so that the entrepreneurs had to find help from their counterparts. This study is an illustration of the whole development process of an RSI. It chooses one special area, and shows the RSI in operation and the historical path through which the RSI reaches its current position.

By and large, RSI can be seen as a System of Innovation at a sub-national level. In recent years, using the region as the analysis unit has aroused more interest in Europe (Storper, 1995). Mainstream economics fails to recognise regional differences thus it is insufficient to explain the real world. Bringing regions back into research purview will help to address important issues. RSI is useful when it deals with special regions which have the following features: (1) even when you isolate this region, it can survive because it almost performs all innovation activities and production activities for a group of products; (2) this region has a special model and the performance of innovation is much better than other regions of the country. In most cases, these regions are located at the core of the relevant NSI too. The essential position of the region is worth examining. As for the mining industry, the regional features are especially striking. The geological structure of the mines, the relative isolation of each mining region from the pre-reform era - all these make the Chinese mining industry demonstrate unique local features which is exactly what RSI attends to.

2.1.3 The Sectoral System of Innovation

Given sophisticated division of labour, sectoral differences have become increasingly obvious. In this epoch of globalization, firms belonging to the same sector learn from each other thereby create a Sectoral System of Innovation (SSI). Pavitt paved the way for creating such a framework, categorising three kinds of firms: (1) Supplier-dominated firms. They can be found mainly in traditional sectors of manufacturing, agriculture, housing etc. They are generally small and weak in in-house R&D. Most innovations come from suppliers of equipment and materials; (2) Production-intensive firms. Firms in this category tend to enlarge in order to utilise economies of scale. They produce a relatively high proportion of their own process technology. They are generally big; (3) Science- based firms. They are to be found in the chemical and electronic/electrical sectors. In both sectors, the main sources of technology are R&D activities, based on rapid development of the sciences in universities and elsewhere (Pavitt, 1984). A commonly accepted definition of SSI is:

"a set of new and established products for specific uses and the set of agents carrying out markets and non-markets interactions for the creation, production and sale of those products" (Malerba, 2002, p.248). Malerba points out several basic elements in an SSI, they are agents, knowledge and learning processes, mechanisms of interaction both within and outside firms, processes of competition and selection (Ibid, p.250-251). He points out that the central concern of an SSI approach is overall dynamics in the population of firms active in a sector and is different from a technological system. In addition, the SSI perspective gets to grip with the geographical boundaries of innovative activities, which are taken as given in the NSI or LSI (Local System of Innovation) (Breschi & Malerba,1997). Geels adds user feedback to this system and turns it into a socio-technical system (Geels, 2004). His theory makes this systematic approach more complete and the demand-side factors enable this system to evolve. Geels' also discusses the mechanism through which one system transfers to a new system. Normally, a system is relatively stable due to the inertia of the actors and various restraining forces. Path-dependence also plays a part because history matters. But it is always possible for radical innovation to enter the niche market. Disruptive innovation is a case in point. Generally disruptive technologies underperform established products in mainstream markets. But they have other features that a few fringes (a generally new) customers value (Christensen, 1997). This kind of technology, will create a new set of criteria to evaluate different products. Lead users at the time this disruptive technology was put into the market tended to ignore or even treat it with contempt. But it will serve as the paradigm breaker because, although in its embryonic stage it was technologically inferior, during its maturity customer support empowered it to overthrow the current hegemonic technology. This is one way to transform the whole system, and it is conducive to illustrate that the instability of an SI might come from any direction. It might cause some tensions, mis-alignment, and instability in the system. This will finally cause the whole system to go through a transformation process (Geels, 2004). In general, the theory of SSI is similar to NSI or RSI. What makes it unique is its practical or empirical importance.

A number of scholars have studied industrial competitiveness through the lens of SSI. In Malerba's book *Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe,* he offers a rough definition: "a sector is a set of activities that are unified by some related product group for a given or emerging demand and that share some basic knowledge" (Malerba, 2004). The main advantages of using the SSI approach is that it can offer a better understanding of: the structure and boundaries of sectors; agents and their interaction; the learning and innovation process specific to a sector; types of sectoral transformation, and the factors at the base of the differential performance of firms and countries in a sector. (Malerba, 2004). Some parts of the SSI framework overlap with NSI or RSI. If, for example, a sector has a national dimension, it means that this sector's firms are country-specific and national institutions and environments are the main focusing device of this sectoral study. In some sectors, the locus of industrial leadership is at the level of the firm. The chemical industry is a case in point (Mowery & Nelson, 1999). Virtually all of today's leading firms in this sector were established many years ago. While in other industries technological leadership may reside at the national level, say, computer software and medical services, the rate of turnover among 'dominant firms' is very high but the shifting collection of dominant firms is composed mainly of those headquartered in the United States. These features are quite sector-specific. Only when you use the SSI approach to study innovation can these features be uncovered. In NSI or RSI studies they might be overwhelmed by other factual data.

There are some other comments to add here. First, the duration and stability of a sector cannot compare with a country or region. A sector is sure to suffer fluctuation. In some cases, if this industry has started to decline nothing can reverse this trend. For countries, history also witnessed the vicissitudes of hegemons and the boom and bust of many economies, but there is always the possibility that a declining economy can recover and be revitalized. Second, NSI, RSI, and SSI can join forces on same innovative processes. The conclusion as to which SI exerts the larger impact can only be answered in an ad hoc fashion. Third, the boundary of a sector is obscure owing to the complicated relationship network between different industrial activities. To make matters worse, these relationships are constantly changing. To conclude, the three SIs all have strengths and weaknesses. They can complement each other. Adopting the philosophy of a System of Innovation is on a par with using an SI optic to observe all innovation phenomenon. The three approaches discussed above are not in conflict with each other, and it is not the case that one can only adopt one of them at any one time. SI is an open system, and any man-demarcated line is possible to create non-existent barriers. In any SI study, the three approaches will be unconsciously used together, although they might be used in an implicit way, as in the current research.

2.1.4 System of Innovation study in relation to China

As a rapidly growing economy, China's economic structure is undergoing a radical change as is China's NSI. There are, unfortunately, not many studies of China's NSI. Lundvall and Gu have produced a small chapter regarding China's NSI, but do not discuss in detail NSI per se (Lundvall & Gu.,2006). In *Asia's innovation systems in transition,* Lundvall et al. define transition as: "a process where one constellation of institutions is turning into a different constellation of institutions" (Ibid). As for the implications relating to innovation, transition also: "reflects a change in the relationship between knowledge producers and knowledge users or the emergence of a new mode of innovation." (Ibid). Combining the SI approach with transition fully demonstrates the instability of an SI and the creative destruction nature of innovation. Furthermore: "the transition perspective challenges the idea that some Asian systems are to be seen as 'models' that can be used as benchmarks for copying by other developing countries" (Ibid, p.2). In the chapter on China, Lundvall and Gu mention policy learning. It is just like what Deng Xiaoping said groping the stone to cross the river. They also discuss triggering factors, sources of policy learning and learning ability, mechanisms of transformation, agencies and their networks, interest-augmentation versus interest-redistribution transformations, and deepening and broadening the knowledge base respectively. By and large, this chapter is a sketchy description of China's NSI albeit a stepping stone for future research. In addition, in a book edited by Parayil and D'Costa the Chinese innovation system is discussed a little (eds Parayil & D'Costa, 2009). They describe the transition of Chinese NSI as turning from a research institute-centred to an enterprise-centred one. While the industry-science linkage has improved in the past 20 years, enterprises in China have evolved from pure manufacturing units to real modern enterprises, though still relatively low in innovation capacity. A number of global giants choose to do R&D in China for the following reasons: ‘proximity to markets and production, utilise Chinese human capital and policy requirement'. These R&D activities conducted by multinational firms and the policies encouraging them have elicited criticism. These policies are seen to be biased against domestic firms and it is unclear whether this has had a positive effect (Ibid). This partly answers the question why, following a sharp increase in R&D spending, Chinese firms are still weak in innovation. There is also an article discussing and comparing two Chinese NSIs at different stages (Liu & White, 2001). It addresses a fundamental weakness of previous NSI studies, namely the lack of system-level explanatory factors. It compares different features of the NSI in a command economy and one under economic transition. It focuses upon five activities in the SI and defines primary actors who undertake one of the five activities and secondary actors whose behaviours affect primary sectors and institutions which are a set of rules and practices. The authors then analysis the two Chinese NSIs. This research is significant since it identifies the transformations of NSI under economic transition. There have been more competitions among actors and more horizontal relationships among primary actors. Two changes which need to be noted are the change in the legitimate criterion for evaluating performance and the decentralization of decision-making over both resource allocation within the economy and the operational decisions of primary actors. There is also a study about the Chinese innovation network (Trupin & Jones, 1997). Trupin and Jones detect a sign that small firms have become more able to conduct innovation in frontier technology: "In China the dominance of large state-owned enterprises in the industrial environment is now being challenged by a rapidly growing private sector…The Chinese government has also retreated from directly steering academic research" (Ibid,). In general, the relationships between different SI actors in China is becoming increasingly decentralised and market-driven.

Apart from the study of NSI in China, some studies look at SSI in China. Lu and Feng (Lu & Feng, 2005) study the Chinese car industry's innovation performance by conducting case studies of three Chinese firms, arriving at the conclusion that only by engaging in indigenous innovation can China's domestic car manufacturers compete globally. Expecting to co-operate with foreign firms and imitate their technologies is not an effective way to enhance Chinese firms' technological capability. Nolan and Zhang (2002) conducted case studies concerning Chinese aerospace and the oil and petrochemical industries and discussed the problems facing Chinese firms after China enters the WTO. In addition, OECD report *Managing National Innovation Systems* discusses some features of developing countries' NSI. They have three similar features. First, the R&D intensity of these economies is relatively low, often below 1% of GDP. Second, these countries' innovative activities, as measured by an index of technological strength, also tend to be quite low compared to high-income economies. Third, the transfer and adoption of technology plays a large role in these countries (OECD, 1999). These features also apply to China.

In short, studies of Chinese firms and innovation are rare and few of them adopt the SI approach.

2.1.5 Summary of the System of Innovation approach

I will use the System of Innovation framework to study innovation activities in the Chinese mining industry. Factors at national, regional, and sectoral levels will be considered in this research. A fundamental principle of the System of Innovation approach is to view innovation as the outcome of a system rather than of any individual actor. When researchers discuss innovation, in theory they should take all the relating contributors into consideration (although this is impossible). In practice, any researcher tends to choose the activities which they give most credit to. The aim of the research can largely determine the perspective the research adopts.[4] This state of the art of this approach is still not developed enough to provide a firm conceptual foundation for some basic fundamental ideas (Edquist, 1997). This theory is still in its infant stage. It needs more theoretical and empirical contributions to become more workable. For example, some scholars argue that: "The innovation

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[4] As I mainly care about technological innovation, another concept needs to be mentioned here, namely, the technological innovation system. "This is a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion, and utilization of variants of a new technology and/or a new product". (Markard and Truffer,2008, p.611)

systems approach, however, may be characterised as myopic with regard to the explanation of technological transitions...The systems perspective, in other words, is inward oriented and does not pay much attention to the system's environment" (Markard & Truffer, 2008, p.610). This could be partly solved by combining other approaches such as the innovation ecosystem which will be discussed later. Just as innovation itself is the outcome of a system, the theories will be adopted to explain how innovation forms a system too. As this research shows, the SI in question will become clearer. By doing this, a more solid foundation can be laid for SI theory.

On the other hand, however, there are criticisms of this approach. It is worth reviewing this literature in the hope of bearing the flaws of the SI approach in mind. However, the criticism of the application of SI to policy-making will be introduced here. First of all, Chaminade and Edquist (2006) point out that the SI approach adopted by OECD actually only takes activities that can be regulated by the public sector into consideration. It fails to give due credit to activities which do not have direct links with policy tools. Rogge and Reichardt (2016) contend that not only does the System of Innovation expose obvious systemic features, but the relevant policies also constitute a system, requiring that the policy makers adopt a systemic perspective to view innovation policies as well. For instance, a policy designed to augment innovation should not only target the demand side. The supply side is also important. Chaminade et al (2012) point out that policies based on the SI approach more often than not end up being one-size-fits-all-policies rather than policies that take the specificities of the system into account. They argue that one of the reasons for this is that we know too little about how to identify and measure specific problems in the system (if it is at all possible), despite several fruitful attempts to define them (p1476). All these criticisms remind the researchers and policy-makers of the gap between theory and reality.

2.2The Triple Helix (University-Industry-Government)

This theory is the analytical tool used for this research, so it will be reviewed first. It originated through developing a new knowledge production model which is called Mode 2 (See Gibbons et al., 1994). In this mode, not only academic institutes but a variety of organisations which do not participate in knowledge-production begin to carry out the task of producing knowledge.

Mode 1	Mode 2
Academic context	Context of application
Disciplinary	Transdisciplinary
Homogeneity	Heterogeneity
Autonomy	Reflexivity/social accountability
Traditional quality control (peer review)	Novel quality control

Figure1: Attributes of Mode 1 and Mode 2 knowledge-production

Source: Hessels and Van Lente, 2008, p.741.

According to Gibbons et al., "Mode 1 refers to a form of knowledge production—a complex of ideas methods, values, norms — that has grown up to control the diffusion of the Newtonian model to more and more fields of enquiry and ensure its compliance with what is considered sound science practice … For many, Mode 1 is identical with what is meant by science. Its cognitive and social norms determine what shall count as significant problems, who shall be allowed to practise science and what constitutes good sciences" (1994, p2-3). While, for Mode 2 knowledge-production, some new practices were found. Gibbons et al (1994, p3-8) explain the attributes of Mode 2 in detail:

> 1.Context of application, such knowledge is intended to be useful to someone in the industry or government; 2. Transdisciplinary. Knowledge produced by Mode 2 will

normally be beyond any single contributing discipline, and it might be the integration of several academic subjects; 3. Heterogeneity. It is heterogeneous in terms of the skills and experience people bring to it; 4. Social accountability and Reflexivity. It has been influenced by growing awareness of the variety of ways in which advances in science and technology can affect the public interest. Individuals engage in knowledge-production themselves and cannot function effectively without reflecting-trying to operate from the standpoint of-all the actors involved, and 5. Novel quality control. Quality is determined by a wider set of criteria which reflects the broadening social composition of the review system. 'Good Science' is no longer limited strictly to the judgements of disciplinary peers'.

This mode extends the knowledge-production network whereas the role of universities in this process are downplayed. Partly as a reply to this mode, the Triple Helix approach was proposed. The Triple Helix[5] (TH) model relocates universities at the centre of knowledge-production networks. In other words, the Triple Helix model regards the university as the core producer of useful knowledge and gives due credit to the contribution made by the university to the advancement of human knowledge. It:

> states that the university can play an enhanced role in innovation and increasingly knowledge-based societies. The underlying model is analytically different from the National System of Innovation approach, which considers the firm as having the leading role in innovation (Etzkowitz & Leydesdorff,2000, p.109).

[5] The term 'helix' refers to a type of smooth space curve, i.e. a curve in three-dimensional space. The two main contributors to the Triple Helix model, Etzkowitz and Leydesdorff, neither explain why they choose this term nor provide a definition. In fact, this term was used due to the popularity of the double helix structure of DNA. They deem that the Triple Helix structure has the potential to bring change to the real world as opposed to the stability brought by the double helix structure.

At first, the Triple Helix refers to Academic-Industry-Government relations, then 'Academic' was replaced by 'University'. According to the two most renowned scholars of this area, Etzkowitz and Leydesdorff (1996, p279): "the three dynamics can be distinguished: the economic dynamics of the market, the internal dynamics of knowledge production, and governance of the interface at different levels". The two scholars also proposed that one implication of the Triple Helix model is the analysis of the binding forces among autonomous, yet tightly connected, institutional arenas (Ibid, p280). The reason for proposing a Triple Helix rather than a double helix is that: "While a co-evolution or a double helix can be stabilized relatively easily, a complex and potentially unstable system emerges when three dynamics interact…The Triple Helix model is sufficiently complex to accommodate various forms of chaotic behaviour in the resulting system" (Ibid, p281).

The TH model depicts some trends worth considering :(1) "Universities and industry, up to now relatively separate and distinct institutional spheres, are each assuming tasks that were formerly largely the province of the other". (Etzkowitz & Leydesdorff,1997); (2) "The role of government in relation to these two spheres is changing in apparently contradictory directions. Governments are offering incentives, on the one hand, and pressing academic institutions, on the other, to go beyond performing the traditional functions of cultural memory, education and research, and make a more direct contribution to 'wealth creation'" (Ibid.); (3) "In the old days, the transfer of knowledge produced by the university to its end-users took place through intermediate agents … Nowadays the university has become a direct producer of goods and services for end-users" (Ibid).

Originally, the three components of this Triple Helix each had its own function which are wealth generation (industry), novelty production (academia), and public control (government).[6]When they: “operate upon each other, mutual shaping in a co-evolution along a particular trajectory is one possible outcome”. (Leydesdorff & Meyer, 2006, p.1441).

There are different forms of Triple Helix relations. In 1998 and 2000, Etzkowitz and Leydesdorff published two papers in which they discuss some possible forms of Triple Helix. In the 1998 paper they identified three main forms of Triple Helix (Leydesdorff & Etzkowitz):

> In Triple Helix I the three spheres are defined institutionally (university, industry, and government). Interaction across otherwise defended boundaries is mediated by organisations such as industrial liaison, technology transfer, and contract offices. In Triple Helix II the helices are defined as different communication systems consisting of the operation of markets, technological innovations, and control at the interfaces. In Triple Helix III the institutional spheres of university, industry, and government, in addition to performing their traditional functions, each assume the roles of the others, with universities creating an industrial penumbra, or performing a quasi-governmental role as a regional or local innovation organiser.

In their 2000 paper (Etzkowitz & Leydesdorff, 2000), they elaborate three configurations of Triple Helix. In the first configuration: “the nation state encompasses academia and industry and directs the relations between them” (Ibid, p111). The second model consists of separate institutional spheres with strong borders dividing them and highly circumscribed relations among the spheres (Ibid). The third model: “is generating a knowledge infrastructure in terms of overlapping

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[6] Leydesdorff (2006, p.23) mentions the: “three functions of the socio-economic system: (1) wealth generation and retention, (2) novelty production, and (3) control”. He does not give detailed definitions of these functions. In this research, the wealth generation function refers to production activities in relation to Karl Marx’s concept of the forces of production. ‘Novelty production’ refers to the exploratory work of knowledge- producers, the outcome of this work being the new understanding of the world. ‘Control’ refers to the norm-setting work of the authorities concerned.

institutional spheres, with each taking the role of the other and with hybrid organisations emerging at the interfaces" (Ibid). In fact, the reality is always more colourful than the theory. The different forms of Triple Helix will be discussed in greater detail in the case study chapter, and will be analysed combined with the cases I choose. These forms are reflections of wider socio-economic configurations and there is no optimum model, there is only a proper model for a specific socio-economic context.

The TH model helps scholars deepen their understanding of universities in the modern world. Universities shoulder a third mission in addition to teaching and research (Etzkowitz & Leydesdorff, 1998, p.203). Universities have been involved in all kinds of business activities and have made direct contributions to countless innovations. Etzkowitz dubs this new form of academic research 'entrepreneurial science'. Universities undertaking entrepreneurial science engage in economic development or, in other words, the `capitalisation of knowledge' (1998, p.824). It is necessary to mention here that there are heated debates about the function and nature of universities both in China and the West. A number of prominent scholars are strongly against the idea of encouraging academic staff in universities to engage in commercial activities. The defenders of the ‘Ivory Tower’ stick to the doctrine that the sole aim of a university should be pushing mankind's cognitive boundaries. They do not underestimate the significance of business achievements, but they draw a clear line between the academic community and industry. Whilst using the framework of the Triple Helix to organise this research, I adopt a neutral stance towards this debate. No normative judgement is made in this thesis about of Entrepreneurial Science.

Meanwhile, as this model mainly focuses upon the functions undertaken by different organisations, the 'nationality' of these organisations will not be stressed. It could be a useful tool to undertake a regional comparison study as it complements the National System of Innovation framework. In their 1998 paper, Leydesdorff and Etzkowitz contend that: “the Triple Helix is mainly a model for analysing innovation in a knowledge-based economy. This model accounts for the phenomenon of emergence, that is, it helps us to understand how the innovation system is based on expectations…More than a single explanation is expected because different perspectives are useful”.

In this research, universities, industry, and government will be regarded as three core players in innovation activities, and the TH model will also be adopted as, compared to the System of Innovation theory, it can better incorporate the R&D of academic institutions. A complete SI study is almost impossible in practice. In most case studies, these three core players receive much attention and most scholars agree that a successful SI will be sure to include positive and efficient interactions between the three. According to Leydesdorff (2012, p.5): “the Triple Helix model enables us to consider empirically whether specific dynamics (e.g., synergies) among the three composing media[7] emerge at national and/or regional levels”.

There is also research discussing the role of firms, universities, and governments in the innovation process, some of which will be reviewed here.

2.2.1 Firms and Innovation

Firm as one helix in the Triple Helix model, the role it plays in innovation process ought to be shed some light. There are many masterpieces about firms, however, only two scholars’ works will be discussed here.

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[7] In this context, the three media refer to power, truth, and money; Luhmann, 1995, quoted from Leydesdorff, 2012.

First of all, I will look at Penrose's *The Theory of the Growth of the Firm* (2009). In this book, Penrose raises the question: 'assuming that some firms can grow, what principles will then govern their growth, and how fast and how long they can grow'. Penrose answers this question from a resource-based point of view, defining 'resource' as "the physical things a firm buys, leases or produces for its own uses… Services on the other hand are the contribution of resources can make to the productive operations of the firm". She also points out that the services that the resource can render are the input of a firm's production process.

The relationship of Penrose's work with innovation consists in the observation that a firm's technological capability influences its growth, and that, with the enhancement of this capability, firms grow. According to her, one important source of the incentive to conduct innovation in a firm are under-utilised productive services. Each firm produces unique resources and related services. The impulse to make the best use of under-utilised resources and services provides the impetus for a firm to grow. Moreover, the accumulation of knowledge gives rise to the discovery of these under-utilised resources and services (Lu, 2000). Thus, innovation is not only closely linked with the growth of a firm, but in fact becomes the prelude for the growth of a firm. The more innovative this firm becomes, the more knowledge of how to find redundant resources this firm can acquire, the faster this firm grows. In short, the outcome of a firm's innovation process determines its future.

Chandler's three monographs followed that of Penrose. In 1962, he published *Strategy and Structure: Chapters in the History of Industrial Enterprises*. In this monograph, Chandler concludes that the structure of big business enterprises follows a strategy. He defines 'strategy' as an overall decision about goals and the allocation of resources to attain them. Meanwhile, technological innovation might create needs and opportunities which can alter the strategy of the business. Finally, this process will end with a decentralised, multipurpose divisional structure at the top and a number of autonomous departments at the bottom. The top managers are in charge of co-ordinating, approving, and planning, mainly making long-term and macro decisions. The autonomous departments are established for manufacturing, selling, purchasing, and research functions.

The second book which will be discussed here is *The Visible Hand: The Managerial Revolution in American Business* (Chandler, 1977). In this book, Chandler divides American business history into two separate phases; pre-1850 and post-1850. He contends that the first phase represents the market economy—one characterised by what economists call 'perfect competition'. The second phase, continuing into the present, represents what he calls 'managerial capitalism'. A managerial revolution occurred around 1850, which marked the watershed of American business history. The significance of this dramatic change is the transfer of the operation of a company from the owner or partners to a full-time salaried managerial group. The pioneer industry in this revolution is the first truly modern enterprise, the railways. Railway companies were the first organisations to have multiple, geographically-dispersed units whose operations needed to be co-ordinated. Prior to the railways, market mechanisms governed and guided the production process. Once the railway companies were established, skilled management took over that capacity. This kind of administrative co-ordination is the so-called 'visible hand'.

The latest research conducted by Chandler that will be introduced here is *Scale and Scope: The Dynamics of Industrial Capitalism* (Chandler,1990). Here, Chandler extends his research field to Europe with a comparative study of the growth of modern business enterprises in the US, the UK, and Germany. He vividly describes the evolution of big business from the late 19th century to the 1930s. According to

Chandler, the UK suffered from the weakness of personal capitalism, its business system remained under the control of founding families focusing upon personal interest rather than the long-term development of the business. While for Germany, Chandler argues that it developed a system of co-operative management in which cartels dampened competitive pressure. The American system is more competitive than that of Germany, although against all odds, the German system proved its efficiency and flexibility in developing modern economies of scale and scope. One important concept Chandler raises is three-pronged investment, which includes investing in plants large enough to realise economies of scale, investing in the distribution networks necessary to inputs and disposal of outputs, and investing in management at different levels. The lack of three-pronged investment explains why Britain was overtaken by America.

To sum up, Chandler's work is a fascinating study of organisational innovation, which has close links with technological innovation. By depicting the interactive history of these two kinds of innovation, Chandler offers a new perspective on innovation. One argument which illuminates the current research is that technological innovation only creates a potential to increase productivity. It is only a necessary condition for the realisation of economic significance, and it is the organisational innovation that helps society to benefit from new technologies. He further contends that organisational innovation will occur only when the technological advancement which can bring economy of speed occurs first, as technological advancement is a challenge for the current structure of the firm and entails a radical managerial revolution. Chandler ingeniously bridges organisational and technological innovation. Echoing Penrose's work, Chandler proposes that a firm's organisational structure could be its core capability and has played a historic role in the growth of most successful firms. This research focuses upon technological innovation in China. In a wider sense, the structure of a System of Innovation is essential to bringing out the best of the resources and services this system can take advantage of. This will be analysed through Chandler's lens. Meanwhile, Chandler states in another work, *Big Business and the Wealth of Nations,* that: "Large industrial enterprises have thus been a substantial part of this economic achievement mainly through the commercialization of new products and new processes which embodied innovating technologies' (Chandler et al. eds,1997, p5-6). Chandler points out that: 'manufacturing enterprises, especially those in capital-intensive and knowledge-intensive industries, have historically accounted for most of the R&D which are essential to continuing technological innovation in the twentieth century' (Ibid, p.24). The lesson that can be drawn is that innovation studies should focus upon large enterprises as they are the prime contributors to innovation. This conclusion echoes Penrose's theory, that is, the growth of a firm and the enhancement of its technological capability are two sides of the same coin. This thesis will test this conclusion in the Chinese context.

A successful Chinese innovation narrative is Huawei, a telecom equipment, software, and services company, based in Shenzhen, a city which borders Hong Kong. It now: "stands out among Chinese companies for its success in penetrating the world's most competitive high technology markets in the high-income countries" (Nolan, 2012). In 2012 Huawei overtook Sweden's Ericsson to become the world's largest telecoms equipment-maker[8]. Initially, Huawei was an agent for simple imported PBX (private branch exchange) equipment. It quickly began to manufacture PBX equipment itself. Faced with the near monopoly established by the global giants among urban customers, Huawei focused upon the decentralised rural market, selling mainly to small local State-Owned Enterprises(SOE) and rural collective enterprises. This 'rural-encircling central cities' strategy was also used by ZTE and 200 other firms in the same field (Fan & Gao,2016). Once it had consolidated its position in its rural 'base areas', it began to compete in urban markets (Ibid). Finally, with the assistance of China Development Bank, Huawei started its walking out process and has achieved great success. In 2015 Huawei had a revenue of US$60,839 million. Its business

[8] http://www.economist.com/node/21559922 viewed on 2017-3-7.

became quite internationalised, while Chinese domestic revenue took only 42.4% of its entire revenue. In the same year, Huawei invested 15.1% of its revenue in R&D, having a R&D talent pool of 79,000 employees.[9] According to the EU R&D Scoreboard 2016, Huawei ranked 8th of the world in terms of R&D investment.

World rank	Name	Country	Industrial sector (ICB-3D)	R&D 2015/16 (€ million)	R&D 1 year growth (%)	R&D 3 years growth (CAGR-3y, %)
1	VOLKSWAGEN	Germany	Automobiles & Parts	13,612.0	3.8	12.7
2	SAMSUNG ELECTRONICS	South Korea	Electronic & Electrical equipment	12,527.9	-1.7	10.7
3	INTEL	US	Technology Hardware & Equipment	11,139.9	5.1	6.1
4	ALPHABET	US	Software & Computer Services	11,053.6	22.4	22.2
5	MICROSOFT	US	Software & Computer Services	11,011.3	-0.5	4.8
6	NOVARTIS	Switzerland	Pharmaceuticals & Biotechnology	9,001.6	-9.5	1.8
7	ROCHE	Switzerland	Pharmaceuticals & Biotechnology	8,640.0	4.7	3.3
8	HUAWEI INVESTMENT & HOLDING CO	China	Technology Hardware & Equipment	8,357.9	46.1	26.3

Table5: Top Eight companies in The EU Industrial R&D Investment Scoreboard 2016

Source：http://iri.jrc.ec.europa.eu/documents/10180/1030082/World 2500 companies ranked by RD.

[9] http://www-file.huawei.com/~/media/CORPORATE/PDF/annual-report/AnnualReport2015_en.p df?la=zh viewed on 2017-3-7.

Huawei's experience is invaluable. During its early years, as a private company without any government support, Huawei's survival largely depended upon how well it served its customers. Huawei tried to be a commercial agent for foreign products, but without productive capacity and technological capability it was unable to keep its customers satisfied. Most of its founders used to be technicians or engineers, choosing to establish an in-house R&D facility for the mere survival of Huawei (Zhang,2009). There were companies whose founders had similar backgrounds, but what enabled Huawei to prevail over its competitors is that Huawei's R&D directly linked with the market. Huawei's technological strength was utilised as a powerful tool to meet its customers' requirements. After going through the toughest years, Huawei did not hide its ambition of becoming the best. In 1997, it launched a re-engineering movement which shifted Huawei from a technology-based competition, to a customer-based approach. This involved a comprehensive transformation of Huawei's culture. This process was so painful that Ren Zhengfei, Huawei' founder, likened it to: "cutting our feet to fit American shoes" (Nolan, 2012). During this re-engineering, the technology giant IBM introduced the process of Integrated Product Development (IPD) which instilled: "the idea of building cross-functional teams focused on particular customers…Teams from across functions now worked together on specific projects, coming from all parts of the company, including marketing and sales" (Ibid). This re-engineering helped Huawei realise the potential of its technological capability and was thus essential to its commercial success thereafter. "The IPD approach introduced by IBM tightly linked the process of product development from one end of the supply chain to the other. The transformation to a system in which the whole process of product development was geared to the specific needs of each customer was revolutionary in the Chinese business system" (Ibid). In a nutshell, Huawei's success in technology comes from its active participation in market competition, by focusing upon serving its customers to survive, while conducting R&D activities became a prerequisite. Being an ICT equipment manufacturer, improving its technical strength and offering a diversity of products to meet customers' needs have become the Huawei ideology. Huawei is very good at combining its technological strength with market signals. It never does research without market prospects. The IPD introduced by IBM brought pioneer management experience to Huawei and further consolidated Huawei's market-technology alliance. The most useful lesson we can learn from Huawei is that technological innovation will only be a useful tool when the company's survival hinges on its customer feedback vis-à-vis product quality. A firm's motivation to engage in R&D is not endogenous, but comes from fierce market competition. Directly facing its customers, gleaning information from the market, marks the starting point of most successful innovation narratives. Failed attempt to improve technological capability occurring in other Chinese industries might be attributed to ignorance of market demands rather than the lack of funding or resolution. Technological innovation is led by both the trajectory of technology and customer demand.

In conclusion, as the subject of innovation, the choices made by firms largely determine the vision of innovation, and the role firms play in the innovation process will be one of the research targets of this thesis. Innovation entails commercialisation, and firms are the major actors in this process. Universities and governments can directly participate but their roles are only secondary. As one of the three institutions of the Triple Helix model, firms might be the only institution that can perform all three functions, Chandler shows that large enterprises are the main driving force for most influential innovations. As an innovation study, the current research will also attach more importance to the contribution of firms.

2.2.2 Universities and Innovation

Etzkowitz undertook a study of the evolution through which American universities began to participate in commercial activities. He proposes that (Etzkowitz, 1989), after the Second World War, the federal government invested a great deal to support American universities' basic research activities. "The lack of significant growth in research funding and the effects of inflation made grants increasingly more difficult to obtain during the 1970s and early 1980s" (Ibid, p.16). Under such circumstances, American universities took advantage of their knowledge base, augmented via federal support, to make university-industry relations salient once more. A number of universities established links with financial or commercial bodies, such as MIT, Columbia, and Harvard. This trend aroused debate over whether this is a good sign for the development of science. Etzkowitz argues that: "changes in the material conditions of scientific work, along with its particular location in the university, are producing changes in the ways scientists and various support personnel think science should be done" (Ibid, p.26). He also predicts that a new norm about how science should be prosecuted is emerging.

Etzkowitz's book *MIT and the Rise of Entrepreneurial Science* (2003) uses MIT as an example to depict the rising process of entrepreneurial universities. He describes how MIT successfully established links with industry and how it has assumed a role whose scope surpasses the notion of the ivory tower. He also introduces the notion of how this model spread to the whole country. He credits MIT with a number of innovations in university governance, such as the 'one day a week' consulting rule, the establishment of a contracts and grants office. Using the Triple Helix model as a frame, Etzkowitz argues that universities play an increasing role in economic development, and this kind of university-industry relationship can free university from relying upon government funding. The conclusion of this book will be tested by this research and the university-industry relationship will be used as a powerful explanatory factor to answer the research question.

While universities undertake more functions, science also takes place in many different areas outside universities and research institutes, and is funded by a range of different sources (Royal Society, 2011). These two phenomena occur simultaneously, as predicted by the Triple Helix model.

2.2.3 Governments and Innovation

Two works discussing American government and innovation will now be introduced. A commonly accepted image of American government is that it adopts a philosophy of laissez-faire, in fact it has initiated a number of S&T projects.

Block (2008) proposes that Europe and America have created a Developmental Network State (DNS), "The main focus of the DNS is to help firms develop product and process innovations that do not yet exist, such as new software applications, new biotech medications, or new medical instruments" (Ibid, p.172). "The difference is that most European nations had stronger twentieth century traditions of active state engagement in the management of the civilian economy than the Unites States" (Ibid. p.174). Block uses one particular office in the Pentagon—the Advanced Projects Research Agency (ARPA), as an example to illustrate how American government acts as a hidden developmental state. ARPA's Information Processing Techniques Office (IPTO) was chosen as it played a central role in the advance of computer technology in the 1960s and 1970s. More specifically, the IPTO provided the resources to create computer science departments at major universities and funded a series of research project that successfully pushed forward advances in the human-computer interface. According to Block, many of the technologies that were ultimately incorporated into the personal computer were developed by ARPA-funded researchers. In that article Block also presents many other examples to understand the huge impact the American state has had on American S&T affairs.

Linda Weiss's work is also illuminating (2014). Over the past 60 years, all the major advanced industries have been pioneered in the US, but: "where does this capacity for transformative innovation come from? Why the United States?" (Ibid. p.3). Weiss looks for the answer in the relationship between high technology, national security, and political culture. She provides three arguments: (1) The national security state (NSS) is a technology enterprise. The 'national security state' refers to: 'a particular cluster of federal agencies that collaborate closely with private actors in pursuit of security related objectives'. In the name of ensuring national security, successive American governments have engaged in a great many activities which aimed at securing American technological supremacy. Governments encourage the R&D in military- related projects and the proliferation of these projects' outcomes to the civilian sector; (2)Geopolitics and related threat perceptions have been the original catalyst for NSS formation and its evolution as an innovation engine, and (3) Weiss argues that: "American anti-statism in the political arena helps to channel government involvement (the commercial activism of the national security agencies) toward a preference for hybrid organisational forms that merge public and private resources in distinctive and often intricate ways" (Ibid,p7).

Gregg undertook a chronological study of the role of successive American governments in the development of the semi-conductor industry (Gregg, 2013). His conclusion is that: "rather than pursing a single centralised semiconductor industrial policy, multiple entities of the U.S. Government have played nuanced and flexible roles in supporting the competitiveness of the U.S. semiconductor industry" (Ibid, p121). Gregg discusses the evolution of industrial policy in different periods of society. This study depicts an interesting phenomenon, namely, the government's role in supporting economic development might change in different developmental stages of a country and an industry.

In a nutshell, government or, in a wider sense, the state can do a lot to facilitate the creation and diffusion of innovation, and they have done so again and again, even the most liberal American government is no exception. However, in a less visible or more indirect way, sufficient evidence has proved that the American government (or, in Block's words, a hidden American developmental state), has attempted to wield its influence in the industrial and academic communities. Besides, studies of the government's role in the Triple Helix demonstrate the different interactive forms between the three helices, which will be further supported in the case study component of this research.

2.2.4 Conclusion of The Triple Helix

After reviewing the extant literature about the Triple Helix and combined with the case study of this research, I would like to distinguish two kinds of Triple Helix model, one institutional, the other functional. I am indebted to Leydesdorff and Meyer (2006). They point out the functions of university, industry, and government in the Triple Helix are novelty production, wealth generation, and public control respectively. The first three can be regarded as three kinds of institutions, therefore we can dub the university-industry-government Triple Helix as an institutional example. The question is that, in reality, in some successful innovation stories one or even two helices may be missing. For instance, universities have little direct impact on equipment manufacture. Under such circumstances, the functional Triple Helix works. This focuses upon the three functions of novelty production, wealth generation, and public control. As long as these functions can be performed, a complete Triple Helix interaction emerges. Sometimes the university as an institution is missing, sometimes the government as an institution is missing, but their missions have been shouldered by others, which means a functional Triple Helix has been constructed.

My case studies demonstrate that the second Triple Helix grasps the essence of this model. One explanation as to why the institutional Triple Helix is more popular is that: “Unlike institutions, functions are not observable without taking a reflexive turn, that is, without some specification of selection environments in terms of expectations” (Leydesdorff & Meyer,2006, p.1442). Turning the focus from formal institutions to necessary functions for the completion of innovations can help a researcher better understand the nature of an innovation process.

In conclusion, the form of a Triple Helix model varies in different countries, industries, and different parts of the value chain. Its nature, however, remains unchanged. All Triple Helix models describe how useful knowledge is produced after the performing of the three core functions, i.e. novelty production, wealth generation, and public control. For proponents of the Triple Helix, these three functions, rather than the real performers of these functions, are the quintessence of an innovation action. Meanwhile, these three functions are also three dimensions of most, if not all, innovation processes. This model can help researchers understand a specific innovation process from three different angles provided by the three dimensions. What is being created and how it is being created determines the co-ordinate of a Triple Helix at each of the three dimensions. Thus, this model is also useful for conducting comparison studies between different innovations. Researchers can create a three-dimensional co-ordinate system consisting of novelty production, wealth generation, and public control, and by locating innovations in this system something valuable can be found. One innovation might contain more wealth generation elements, another innovation might contain more novelty production elements. The structure of the case study in this research will be framed according to the idea of the Triple Helix. The two kinds of Triple Helix will also be demonstrated in greater detail.

Bearing this in mind reminds a researcher that innovations are either being done by at least these three bodies or cannot be completed by performing three functions. Meanwhile, identifying which kind of Triple Helix Chinese TH relations belong to is also an important task, helping to locate problems thus leading to future progress.

2.3 The Innovation Ecosystem

“An ecosystem is a community of living organisms in conjunction with the non-living components of their environment (things like air, water and mineral soil), interacting as a system” (Wikipedia, 2016). Scholars use this concept in innovation studies in order to help better understand the dynamic nature of innovation. Adner (2006) describes innovation ecosystems as: "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution" (p. 98).

Innovation is a socio-economic phenomenon features with uncertainty and breaking the equilibrium. The general image of a system, however, is stable unlike the real-life innovation process. Jucevicius and Grumadaite argue that: "The literature on 'Systems of Innovation' has been largely dominated by the institutional list approaches with emphasis on the structural aspects of the innovation systems" (2014, p.125). "However, it is of limited value for achieving a truly functioning innovation system because it fails to take into account its complex social dynamics" (Ibid).

The advantages of the innovation ecosystem's in portraying a dynamic picture of innovation are manifold. First of all, innovation ecosystems focus upon the function of the system rather than the component. For instance, Fransman (2010) analyses the three layers of an ICT ecosystem which are intra-firm, interfirm, and institutional environment. He stresses the production, competition, and co-operative functions during knowledge-production activities. Moreover, more importance is attributed to the environments of innovation. Stanford University's Innovation Ecosystem Network defines an innovation ecosystem as: "the inter-organizational, political, economic, environmental, and technological systems through which a milieu conducive to business growth is catalyzed, sustained, and supported" (Phlinkiene & Maciulis, 2014, p366). This definition stresses the relative independence of the innovation environment as it is through the milieu that an innovation ecosystem realises its function of facilitating innovation.

The flaws of this theory are also discussed by scholars. Mokyr (2002) points out that the biological analogy is based on experience and intuition, a solid micro theoretical foundation is absent, in fact, the evolution of the ecology is different from evolutionary mechanisms of human knowledge and technology. Papaioannou et al. 2009) argue that the eco-thinking does not adequately capture the distinction between innovation events and structures while the environment of knowledge and innovation includes complex social interrelations and networks which are historically developed. This implies that it does not involve a functional process of adaptation but an uneven and contradictory process of both co-operative and conflicting relations generated by the separations of the social division of labour. Just as Fransman (2010, preface, p17) points out:

> Ultimately it is the creative leap of the human mind – as new associations, inferences and connexions are made – that constitutes a rupture from the past and causes movement in the socio-economic ecosystem. But this creative leap does not have a counterpart in the biological or physical worlds. It cannot be equated with the mutations and chaotic non-linear interactions that drive change in the natural world, even though there may be some similarities in their systemic consequences. The human act of creation is not a mutation but a regular part of the functioning of the human mind.

In summary, systems of innovation, Triple Helix, and innovation ecosystems adopt different optics to view innovation. They have their own advantages and disadvantages, and this research is indebted to all of them.

2.4 The Mining industry

Unlike the common image of mining as a sunset industry, in a project undertaken by the Brookings Institute metal ore mining is considered to be an advanced industry (Muro et al, 2015). This categorisation is based on two criteria: 1. an industry's R&D spending per worker must fall in the 80^{th} percentile of industries or higher, exceeding $450 per worker, and 2. the share of workers in an industry whose occupations require a high degree of STEM knowledge must also be above the national average, or 21% of all workers (Ibid, p.2). The American story at least proves the technology intensity of mining. This is not an industry which pays little attention to technological advancement. According to the EU R&D Scoreboard, 11 mining companies' R&D investments were ranked the top 2,500 in the world:

World rank	Name	Country	R&D 15/16(€ million)	R&D 1 year growth (%)
270	VALE	Brazil	438.1	-35.0
896	RIO TINTO	UK	95.5	-7.1
1065	ANGLO-AMERICAN	UK	76.2	-17.8
1365	BOLIDEN	Sweden	54.7	27.0
1434	ZIJIN MINING	China	50.7	75.1
1599	DOWA	Japan	42.6	5.2
1851	LKAB	Sweden	34.6	-26.7
1890	JOY GLOBAL	US	33.3	-10.8
1972	TECK RESOURCES	Canada	31.2	135.0
2232	HUNAN GOLD	China	25.5	10.9
2465	SHANDONG GOLD MINING	China	21.9	-7.5

Table6: Mining companies on The EU Industrial R&D Investment Scoreboard 2016.

Source： http://iri.jrc.ec.europa.eu/documents/10180/1030082/World 2500 companies ranked by R&D.

Mining is mainly about extracting natural resources. Hence many journal papers and monographs have discussed the abundance of natural resources together with economic growth. Some scholars arrive at the conclusion that natural resource abundant countries have experienced slow economic growth and dub this phenomenon 'resource curse'. Gylfason et al, argue that a productive low-skill intensive primary sector causes currency to appreciate in real terms thus hampering the development of a high-skill-intensive secondary sector thereby reducing growth. Moreover, the volatility of the primary sector generates real-exchange-rate uncertainty and may thus reduce investment and learning in the secondary sector (1999). Other scholars note that resource abundant countries tended to be high-price economies and that, partly as a consequence, these countries tend to miss out on export-led growth (Sachs & Warner, 2001). This point of view, however, is far from reaching a consensus among researchers. In a book edited by Lederman and Maloney, a group of scholars attack the methodology adopted by previous scholars and point out that natural resource is neither a curse nor a destiny. Some natural resource-rich countries have become highly developed, such as the USA, Canada, Australia, and Nordic countries. Whether countries can take advantage of their natural resource endowments hinges on when the natural resources were found, whether the education level and infrastructure level is high enough to grasp the opportunities (eds Lederman & Maloney, 2007). If the country possesses enough human capital, natural resources can be an impetus to the economy. From the perspective of SI, if the country's NSI adds more value to the extracted natural resources and facilitates their introduction into the innovation process, resources can be a blessing. Otherwise, the country can only export the extracted resources and is unable to utilise them in manufacturing final products. In this scenario, resources become a curse.

Mining also has several clear-cut stages, including broad geographical surveys, regional and detailed exploration, detailed orebody delineation and evaluation, mine development, plant construction, as well as exploitation (Bosson & Varon, 1977). Due to the strategical significance of the mining industry, major issues are seldom purely economic but usually political economy issues. As the reserves in developed countries are depleted, giant multinational mining companies are exploring new mining fields in developing countries, thus the question of property arises. The highly unequal distribution only makes the matter worse. Co-operation between developing countries with multinational companies are critical.

Mining is cross-influenced by NSI and SSI. Innovation. Not too many innovation studies have been done in this area. This research could help to fill the gap. This industry is also heavily influenced by policy, especially in developing countries. In developed countries, mining firms tend to be privately owned while in developing countries SOEs are the main players (Mikesell & Whitney, 1987). Different ownership influences firms' business tactics. Meanwhile, as the topic of sustainable development is under discussion, the mining industry will bear the brunt because it is considered to be the main environmental polluter. All these factors call for a study of mining from a fresh angle and literature of this sphere is lacking.

When it comes to the Chinese coal mining industry, Nolan studied the Shenhua Company (2001a). Shenhua was established to take advantage of Shenfu Dongsheng coalfield and is 100% owned by the state. The reserves in this coalfield are large and the quality of the coal is high. Nolan discusses the development of the company, such as transport problems, finance barriers, and labour productivity. This research is a case study for an important coal company in China but it did not touch on innovation. Rui also conducted a study of the Chinese mining industry. It examines:

> how the three parallel challenges from development, transition and globalisation determine that reform must be handled cautiously experimentally innovatively and in a balanced way, with the state playing a significant and irreplaceable role (Rui,2005).

She uses the development of Township and Village Enterprises, Jixin Mining Bureau, and Shenhua Group to illustrate the gradualist philosophy that underpins Chinese reforms. Neither of the two studies, however, choose technological innovation as their main target. They discuss industrial policy and the development strategy of the mining industry, their analysis is at the macro level. My research is a micro or meso-level study. I specifically point out that innovation is the key to the industry's development, and future industrial policy will give due credit to innovation. Rui, et al also discuss the policy of making coal-power bases in China (Rui, Morse & He, 2010). The key arguments of their report are that, first, the coal industry faces severe challenges despite its impressive restructuring. Second, integrating coal and power businesses at key sites is one of the most significant reforms. Finally, the three authors predict that coal power integration reform is not likely to bring dramatic change in the near future, but it might alter the course of this industry in a 10-year time frame (Ibid, p.4).

Nolan and Rui (2004) researched the period after China entered the WTO, focusing upon how the Chinese government should use industrial policy to support the development of its economy. Their paper uses the coal industry and Shenhua as examples. It argues the mainstream opinion that it is the market mechanism rather than industrial policy that should be regarded as the best way to guide a country's economy. In fact, for China as a developing country, some well-designed industrial policy is needed, and Shenhua is the best example to illustrate what a huge impact these policies could have on a company's growth process. It mentions the national support for Shenhua is helpful in providing funding for equipment and technology purchasing, a theme which is directly related to the current research.

3 Methodology

This research is conducted mainly by using qualitative methods.

3.1 Case Studies

Coal mining, non-ferrous metal mining, and mining equipment manufacture are selected as the themes of the case studies. According to Gerring, a case study is an: "intensive study of a single unit for the purpose of understanding a larger class of (similar) units. A unit connotes a spatially bounded phenomenon—e.g., a nation-state, revolution, political party, election, or person—observed at a single point in time or over some delimited period of time" (2004, p342). These two branches of the Chinese mining industry help me to detect and discover the incarnation of Chinese NSI at a much lower level. Also, Gerring describes several merits of conducting case studies, some of which are relevant to this research. For example, he states that: (1) inferences are descriptive rather than causal, and I intend to acquire knowledge about Chinese NSI, which is a typical descriptive inference; (2) insights into causal mechanisms are more important than causal effects. I am more interested in learning why Chinese firms are not innovative enough; I am not so interested in their innovative performance, and (3) when the strategy of research is exploratory rather than confirmatory. Few people have done research similar to mine and references to my research question are far from reaching a unanimous conclusion. Although I would like to know a proposition prized more in breadth (about the whole NSI of China), it is impossible for PhD research. So in my research, depth is given more credit. Based on the foregoing, case studies seem more apposite.

This study covers the different levels of analysis of NSI described by the OECD report (OECD,1999). First, the micro level is considered, w ith a: "focus on the internal capabilities of the firm and on the links surrounding one or a few firms" (Ibid,24). Then the meso level, which: “examines knowledge links among interacting firms with common characteristics, using three main clustering approaches: sectoral spatial and functional” (Ibid, p.24). Finally, the macro level, which: "uses two approaches: macro-clustering and functional analysis of knowledge flows" (Ibid, p.24). I combine the three levels of analysis to conduct my research but pay differing attention to each of the three.

3.2 In-depth interview

Innovations are collective outcomes. A great number of people participate in this process, making their own contributions, though varying in degrees. Thus, I conducted interviews with R&D personnel, engineers working on the production line, managers, workers, research staff in universities or public laboratories, consumers of the products, as well as equipment suppliers. I also interviewed science policy-makers. All of them play unique and indispensable roles in the whole System of Innovation. A better SI should be able to provide platforms for these people to enhance and smooth their communications, thereby facilitating the flow of knowledge within the system. Innovation is the creation of knowledge, and entails collective learning, hence the System of Innovation-building should include infrastructure building to exchange and diffuse knowledge. By interviewing the people involved, I can gain precious knowledge about the SI in operation.

With respect to R&D personnel, I asked them to describe their working details, their main tasks, whether they have daily contact with the machine users and information about the market survey, and whether their technical solutions to the problems facing the firm are praised or ignored. Engineers, on the other hand, offer technical services. Compared with R&D personnel, they are more directly linked with practical work, while R&D personnel are closer to the theoretical work and do not usually attend production or go to the factories. I would like to know whom they most often turn to for help when they have problems with machines, how they view their relationship with R&D personnel and the importance of having in-house R&D, whether the engineers care about the complaints and the needs of workers, and whether workers' feedback is an important source of improvement.

Regarding research staff, I asked them to make comments on their links with industry. For example, do they think this is a main funding source? Do they think their co-ordination with industry is a distraction from their own research or could it increase mutual interests? Do they think the basic research they are engaged in can be helpful to industry, and if so how? The above three groups of people can be subsumed into higher status categories in innovation, in that they tend to be better educated than other players. Their view of themselves and their interactions can set the tone for the whole system, as it is they who create most knowledge in the system.

Workers, meanwhile, are the direct users of any machines and the direct benefactors of technological innovation. In the Japanese production model, even these ordinary workers are regarded as an important source of innovation. Indeed, some scholars argue that this is the very reason why Japan overtook America and Europe after the Second World War (Lazonick, 1990). Thus, I visited several factories to witness their status and production organisation, and also to consult the workers about their understanding of their positions in the firm and their influence on managerial and technical staff. In innovation activities, workers constitute most of the population but their status is often looked down upon. In some cases, they are treated as fungible components. But in other cases, they not only enjoy high social status but also actively participate in innovation. My prime concerns are whether the two contrasting situations exist in China and what are the possible mechanisms by which they influence innovation outcomes.

Regarding managers, it should to be noted that they seldom directly participate in technological innovation (while they are responsible for most organisational innovations), but their governance skills always serve as the catalyst of innovation. Without support from the top, be it financial or institutional, innovators do not have sufficient energy to propel innovation. These managers make a firm's strategic decisions, and their resolution of problems will determine the firm's development trajectory. As innovation will always be accompanied by risk and uncertainty, many managers might regard it as the last resort or may not even list innovation in their toolkit. In history, only those firms whose managers have strategic intent have achieved great success. The strategy is not to copy competitors or reduce production costs. The winners ask what must be done differently and planners ask how next year be different (Hamel & Prahalad, 2005). Managers' perceptions of innovation are pivotal to this firm's attitude towards innovation. Thus, I asked these managers whether they give innovation priority when they tackle technical problems, and whether they prefer indigenous innovation or to contact experts outside the firm for help.

Consumers' needs have long been studied by innovation scholars and business scholars alike. Likewise, supply and demand seems to be an eternal topic. NSI's one theoretical strength is to take consumers' needs into account. During my interviews, I tried to gain access to the lead users of the products. As von Hipple argues in respect to new products, especially radical new products, lead users (users whose strong present needs will become general in a marketplace months or years in the future) can serve as a need-forecasting laboratory for marketing research (von Hipple, 1986). Hence, I did not conduct too many interviews with average consumers or final product consumers but with consumers who have the ability to undertake further innovations. Their feedback can put heavy pressure on the supply chain and might have a cascade effect on all the participants (Nolan at el., 2007). These interviews helped me understand the relationships between upstream and downstream firms. Interviews with suppliers bear similar goals and are especially important for firms belonging to the supplier-dominated category.

Policy-makers are also important actors. They possess the political power to regulate industries and should assume the obligation to help firms pool risk and reduce dangers. 'Good' policy should create incentives for firms to undertake innovation, while 'bad' policy might impose a soft budget on firms so that they can survive quite well without shouldering the burden of innovation. Of course, the terms 'good' and 'bad' have only relative significance. In this context, they refer to whether this policy encourages or discourages innovation. Whilst policy-makers cannot innovate themselves, they can use policy to remove barriers which impede innovation and establish supporting services to allow innovation to flourish. Historically, any successful innovative country must have had an innovation-friendly political environment: "The state has played a leading entrepreneurial role in achieving innovation-led growth. State-funded organisations have been fundamentally involved in generating radically new products and processes, which have changed the way that businesses operate and citizens live" (Mazzucato, 2011, p115). For example, all the core technologies of the iPhone can be traced back to government agencies. In the Chinese context, the government still enjoys unchallenged power in many areas and retreating from daily administration work is seen as shirking responsibility. Policy-makers ought to be fully aware their historic mission. SI's one aim is to produce policy implications. This function's contribution to innovation can never be overestimated.

All the aforementioned groups of people constitute the core part of an SI, and their interactions also belong to an SI. By interviewing them, an SI in operation can be clearly portrayed.

3.3 History Studies

In any SI study, history matters, since no SI is created in an institutional vacuum. Even though new institutions often supersede old institutions, the older institutional regimes' influence still lingers, and understanding the past trajectory can help us predict the future trajectory. China is today going through radical institutional change and, just as a famous emperor in the Tang Dynasty said: "Using history as a mirror, you can understand the vicissitudes of different regimes." Chinese policy-makers have made various mistakes (and many correct decisions), thus learning from them will avoid making the same mistakes and leads to best practice.

4 An Empirical Study of the Chinese Mining Industry

Mining has a long history in China, whereas only after the reform and opening-up did it enjoy rapid technological advancement. During the pre-reform era, the industrialisation process in China had given the mining industry a major boost. Millions of workers and billions of yuan were invested in this industry. The social status of miners in China can be vividly illustrated in the parade at Tiananmen Square on National Day. The mining workers' legions always appear at the front. Some miners became national heroes like Stakhanov in the Soviet Union. During pre-reform period, the foundation of mining was laid, as was the mining industry's Sectoral System of Innovation. All the ensuing changes have been based on this system.

The major discovery of this part of my research is that if we divide the whole industry of mining into four stages, an inter-stage innovation performance gap can be found. The mining and processing stage are more innovative than prospecting stage and equipment manufacturing. The causes of this divergence wil be further elaborated with the case studies in the fifth chapter.

4.1 The Chinese mining industry in history

This section will be a brief introduction to the history of coal mining and non-ferrous metal mining in China. History helps us to understand some seemingly illogical phenomena, and as Chinese history, especially the period after the founding of the PRC, is quite unfamiliar to foreigners, there now follows some orientation.

4.1.1 The history of coal mining industry in China[10]

4.1.1.1 General Information

Coal mining has a long history in China, but this section will focus upon the PRC

[10] The information in this section is based on *The History of the Chinese Coal Mining Industry* (中国煤炭志), 1999.

period. It is reported that, around 1950, the PRC owned about 40 coal mining companies and 20 open-cast mines, most of which were small and did not have advanced technology. In November 1949, the Ministry of Fuel Industry was established and put in charge of the construction and restoration of coal mines. Some new mining methods, such as the longwall method, were encouraged and some old-fashioned mining methods were eliminated. The Ministry did a great deal to guarantee the demand of other industries for coal and with the co-operation of the coal mines' cadres, technicians, and miners by the end of 1952, 83% of the state-owned coal mines had recovered normal production conditions. In that year, the total production capacity of Chinese coal mines was 70 million tons, higher than any previous year. In the meantime, 13 new mines were constructed in the northeast.

During the first Five Year Plan (1953-1957), the whole country saw an era of large-scale economic development. Many industries' demand for coal soared, and the coal mining industry entered a period of rapid development. First, a number of new mining sites were chosen and new mines were built. Seven coal field geological survey bureaus, eight coal mine construction bureaus (companies), five design institutes and one coal processing institute were established. Second, in the past most coal mines were located in the northeast region. This geographical distribution needed to be changed, and new mines were built based on the local need for coals as well as national defence considerations. At the end of 1957, the production capacity of new coal mines was 75.37 million tons, and prospecting teams did exploration work in 72 coal fields. Some mechanised mining methods were also applied and productivity grew.

During the second Five Year Plan (1958-1962), the main targets of the coal mining industry were to strengthen its prospecting, design, and construction workforce, accelerate the construction of coal washing factories, and improve the coal washing technology. Meanwhile, the range of coal being produced were broadened. During the Great Leap Forward (GLF,1958-1960), however, the coal mining industry suffered heavy losses. Only 10% of the coal mines under construction during this period could be finished owing to unreasonable design indicators. Only 60 geological reports out of 474 were qualified reports. Fortunately, in the wake of the GLF movement, the Chinese Communist Party recognised the fault of the movement and adjusted its policies. In 1965, the coal mining industry had recovered from the GLF, the production capacity of that year was 230 million tons, 20 million tons higher than in 1962. Forty new mining regions were developed, 423 new mines were constructed, and some coal fields were discovered.

During the third Five Year Plan (1963-1967), because of the Cultural Revolution, the coal mining industry suffered greatly, as had the whole of China. Against all odds, the production capacity of Chinese mining industry rose from 354 million tons at the end of the third Five Year Plan to 482 million tons at the end of the fourth Five Year Plan (1968-1972). During this ten-year period, production plants were moved to the hinterland in order to increase their rate of survival during wars, and a number of coal mines were built in southern China because the southern provinces needed coal to ignite their economies. Following these developments, the lever of coal production was not as lopsided as it had been. In 1976, when the Cultural Revolution ended, the production quantity of coal was 483 million tons, 92.9% higher than 1966.

Shortly after the Cultural Revolution, coal mining entered a new epoch. Technology began to play an important role. China bought 100 sets of mechanised equipment from western countries and put them to work. A variety of equipment and technology were introduced in coal mines, such as fire extinguishers and gas monitoring equipment. In 1985 China produced 872 million tons of coal. A more humane management style was adopted, canteens, kindergartens, primary schools were built in the mining regions, and the relatives of miners who lived in the countryside were provided accommodation and other welfare.

The theme of the ensuing period is reform, and reforms occurred in many sub-fields of coal mining. In the management field, the central plan was no longer the sole source of a company's strategy. The autonomy of coal mines was expanded, the salaries of miners were linked with production performance, the production and sale of coal were unified. In 1986, China produced 894 million tons of coal. This figure ascended to 1.08 billion tons in 1990, helping China become the largest producer of coal in the world. The productivity and the safety of miners were improved too. Privately owned mines appeared in this period, and by 1990 there were around 33,000 privately owned coal mines. Tibet even constructed a coal mine at an altitude of 5,100 metres. In summary, the coal mining industry had been a fast-track industry ever since.

4.1.1.2 Science, Technology and Technology Policy

The role science and technology played in the corresponding period also changed, as did the attitude of regulators towards science and technology. In early 1950s the guiding philosophy of R&D in coal mining was to learn from the master, the Soviet Union. Prior to the founding of the PRC, the capitalist owners of coal mines adopted an exploited way of mining, and little technology was used during the mining process. The capitalists cared only about how to reduce costs and only ran mines at locations where the coal seam was thick and the quality of the coal high enough. Shortly after the establishment of the Ministry of Fuel Industry, mines were spurred to learn from the Soviet Union. A technological reform was launched centred on mining technology, through the way of making technology policy, scientific and technological development plan and safety regulations. Different kinds of machines were introduced such as electric drills and longwall mining equipment. From this period, technology and science began to play a greater role in Chinese coal mining.

Influenced by the GLF movement, in around 1960 the coal mining regulator set unreachable targets for scientists and engineers to fulfil. The popular slogan 'overtake Britain and surpass America' was the popular maxim of the day. The results were negative, with even some achievements in the previous period discarded. When the GLF was abandoned, a new round of adjustment began, and a new institute, the Beijing Coal Science Research Institute, became central to the field. This was an institution evaluate scientific and technological achievements in coal mining, and the authorities concerned decided to summarise successful experiences of adopting new technology all over China. Sixteen advanced rock tunnelling technology were selected and introduced to all coal mines in China. A new standardisation agency was established, and the productivity of mining tunnelling was improved. Besides, the single-minded urge to learn from the Soviet Union was challenged. As at that time the PRC had not established official diplomatic relationships with most western countries, a series of exchange activities were organised by the Chinese Academy of Coal Science. Chinese engineers and scientists came to Britain, Germany, and France to exchange information and visited equipment manufacturing companies. The basic work done in this period laid the foundation for future development.

The following period was marked by reforms in mechanisation. As China lacked oil and gas, coal became the most important primary energy source, while as the Chinese economy grew, the lack of coal would be a severe problem. Following visits to European countries, policy-makers and regulators recognised that only by launching mechanisation reform could the coal mining industry provide sufficient product to other industries. Hydraulic support and coal excavation machines became the main foci. In 1973 the coal industry was allowed to purchase equipment from West Germany, Britain, and France. Based on this equipment, other equipment was designed and manufactured by Chinese engineers and tested on various occasions.

The significance of science and technology increased a great deal during the reform and opening-up period. The Sectoral System of Innovation in Chinese mining came to mimic that of developed countries. Firms were regarded as the subject of technological advancement, some policies aimed at encouraging mining firms to attach more importance to technology were issued, and coal mining companies gained more autonomy, as did the research institutes. The institutes were freer to allocate their funds to sign new contracts with other organisations. Some experts formed a group to investigate the current situation in coal mining and proposed several suggestions such as encouraging exports, establishing a special fund to support mechanisation. In the 1980s, the positive interrelationship between science, technology, and economic development was stated explicitly by Deng Xiaoping, and coal mining was expected to realise this positive interaction. The technological reform of mining firms was supported, in-house R&D agencies were also supported, while criteria to evaluate how much a firm relied upon technological advancement were designed. Moreover, during this period the Chinese mining industry adopted a new import strategy. Relevant manufacturing equipment, technological materials, testing equipment and technology were purchased. This change was aimed at facilitating the understanding of Chinese technicians towards state-of-the-art technology and to shorten the time it took Chinese technicians to produce these equipment in China. With the hard work of engineers, technicians, and scientists, the technical capability of Chinese coal mining was augmented.

During the same period, the form of technological policies saw changes. Prior to 1960, there were no written technological policies about the coal mining industry. During the 1960s, the State Scientific and Technological Commission[11] convened a conference on technology policy, and all industries were asked to draw up technological development plans. The plan formulated by the coal mining industry was a detailed instruction. It set out clear technological goals for coal mines, while some advanced technologies were recommended to the industry. However, this top-down technological route map was not officially implemented. After the Cultural Revolution, the plan was discussed, edited, and finally became official policy in 1979. Unfortunately, the policy reflected the situation in the 1960s, so it was out of date by

[11] The predecessor of the Ministry of Science and Technology.

the early 1980s. Some frontier technologies had been used, some new regulations regarding the protection of the environment and the ownership of land were issued, and they were seen as relevant to coal mining. A new technological policy was badly needed. In 1987 a new coal industry technology policy was implemented, some technological indicators were updated, opencast mines, environmental protection, and the ground equipment of coal mines were added. To sum up, technology policies prior to 1990 bore typical features of a centrally planned economy, while coal mines had less autonomy to develop technology, but this system was efficient in promoting technology or equipment which have proved to be useful.

China's first coal-related research institute was established in Fushun city, Liaoning province in 1953. Its research domain was mainly coal mine safety. In 1956, the Beijing Coal Science Research Institute was established, its research fields covering coal field geology, coal chemistry, coal mine engineering technology etc. Prior to the Cultural Revolution, there were seven non-Beijing coal-related research institutes. They were under the regulation of the Ministry of Coal Industry[12] and the local governments. As these institutes served the whole country rather than their hosting province or city, in the 1980s the Ministry of Coal Industry was once more empowered to regulate these institutes. In 1990 17 research institutes were affiliated to the Ministry of Coal Industry, and 4,204 scientific and technological employees worked for them. A complete research system was established and co-operation with America, Japan, Germany was also institutionalised. The institutes undertook different research tasks at different times. Until early 1980s, governments were in charge of providing funding to the institutes, after that they were encouraged to contact coal mines to receive research funding. The government branch in charge of managing these affairs was The Department of Technology

[12] The Ministry of Coal Industry was established in 1955. In 1970, it merged with other ministries to form a Ministry of Fuel Industry, its name has changed several times since then.

There are also some universities affiliated to the Ministry of Coal Industry. Prior to the founding of the PRC, over 90% of coal miners were illiterate or semi-illiterate. The PRC's coal industry regulation agency opened a number of secondary vocational schools to train the miners and seven universities were established. They became the vital pillar of coal mining industry, their main task was teaching, not research, which is the task of research institutes. All these education institutes belonged to the Ministry of Coal Industry and they directly send their graduates to coal mines, which can be seen as the basis for the Triple Helix of mining in China.

4.1.1.3 Coal Equipment Manufacturing

Coal equipment manufacturing was established from an almost zero basis. In 1949, 1950, and 1951, three coal machinery firms were established at Jixi city, Zhangjiakou city, and Huainan city respectively. These firms paved the way for future coal machinery manufacturing and accumulated precious expertise. In 1955 the Ministry of Coal Industry was established. From then on, the general-purpose machinery was under the regulation of the Ministry of Machinery Industry, while the coal mining equipment was the turf of the Ministry of Coal Industry. The Chinese coal equipment also began to be based on learning from The Soviet Union, imitating Russian products, and domestic firms finally possessed the ability to produce implements. During pre-reform period China could only produce simple machinery such as scraper conveyers. Then some new factories were built at Beijing, Shanghai, Xi'an, and other cities. The product list became more complete. In 1964 Zhangjiakou and Jixi developed the first Chinese designed and made mechanised mining equipment. During the Cultural Revolution, a number of coal machinery factories moved to the hinterland and normal production was severely affected until they moved back to their original sites after the end of that political disaster. During the reform and opening-up period, equipment firms got higher autonomy, they actively engaged in international co-operation and imported advanced production line, testing technology. By the end of the 1980s, there were 36 key coal machinery firms.

From this brief history, we see that the Socialist Construction, the Great Leap Forward, the Cultural Revolution, and the Reform and Opening-up are important events which exerted enormous impacts on every aspect of coal mining. The relative professional management of state agencies set the basic tone and trajectory for the future development of the industry.

4.1.2 The history of the non-ferrous metal industry in China[13]

The history of the Chinese non-ferrous metal industry can be divided into two stages, the pre-reform and opening-up era and the Reform and Opening-up era. Each lasted about 30 years.

4.1.2.1 General Information

The production history of non-ferrous metal in China can be traced back to at least the Shang dynasty (about 1600 B.C. to 1000 B.C), and China used to possess the most advanced technology. But like other industries, this industry lagged far behind the West in late Qing dynasty (1644-1912), especially after the industrial revolution. In 1949 the production quantity of 10 kinds of non-ferrous metals was 13.3 thousand tons only. After the founding of the PRC, some non-ferrous metal factories and mines quickly recovered and from 1952 the production quantity of 10 kinds of non-ferrous metal was 74,000 tons. During the first Five Year Plan, the Soviet Union assisted 13 non-ferrous metal related projects, some new mines were developed and new technologies were utilised. At the end of this period, the production quantity of 10 kinds of non-ferrous metal rose to 215,000 tons. The coming two decades witnessed political turmoil and economic upheaval in China. The non-ferrous metal industry suffered dramatic fluctuations in its fortunes, although the production quantity of 10 kinds of non-ferrous metal reached almost a million tons in 1978. The industry's most fundamental achievements during this period were to establish a relatively complete industry chain from prospecting to metallurgy, and to foster the ability to produce a

[13] The content of this section makes reference to 'The sixty years history of PRC's non-ferrous metal industry' edited by the China Non-ferrous Metal Industry Association.

wide range of products, to which all ensuing development would be indebted.

The Reform and Opening-up period is now regarded as the golden age of non-ferrous metal industry. A reform to decentralise the industry was launched, and not only the state but the individuals became qualified to run a company. In 1983 the State Council agreed to establish a state-owned enterprise to be in charge of regulating the non-ferrous metal industry. This year might be regarded as the independent year of non-ferrous metal industry, during which aluminium, copper, nickel, lead and zinc mining received credit from this SOE. In 1992 the production quantity of 10 kinds of non-ferrous metal increased to almost three million tons. In the 1990s the non-ferrous metal industry, together with other industries, saw dramatic development. In the mid-1990s numerous SOEs faced the prospect of going bankrupt, lots of workers were sacked, the 'iron-rice-bowl' was no longer an employment guarantee, and s counterparts from other industries began to invest in non-ferrous metal, which boosted the industry. In 2002 the production quantity of 10 kinds of non-ferrous metal was 10.12 million tons, and China overtook America to become the largest producer in the world. The 2008 figure, was 251.2 million tons. Meanwhile, the revenue of the non-ferrous metal industry also increased exponentially. In 1950 the whole industry's revenue was only 26.14 million yuan. This figure soared to 8.43 billion yuan in 1978, and then further increased to 1.9 trillion yuan in 2007. As for the industry's profit, it was only 8.44 million yuan in 1950, 1.22 billion yuan in 1978, and 146.4 billion yuan in 2007. The international trade in non-ferrous metals also enjoyed sharp growth. In 1949 the total volume of imports and exports of non-ferrous metal was US$290 million, the corresponding figure for 1978 was US$810 million, and in 2008 it rose to US$87.4 billion. In 2008 the structure of the capital volume of non-ferrous metal enterprises above a designated size was quite diverse. SOEs only took up about 44% of total capital volume. Privately owned, Hongkong-based, and Taiwanese companies as well as multinational companies all participate in non-ferrous metal mining in China. Besides, the international status of the Chinese non-ferrous metal industry is unmatched by any other countries. It produced 40% of the world's tin, 85% of antimony, 80% of magnesium (Mg), and 85% of rare earth. The production and refining of copper, aluminium, and lead are also number one in the world. This status confers upon China a bargaining power with other users of non-ferrous metal. It also provides potential opportunities for China to upgrade its production plants.

4.1.2.2 Non-ferrous Metal-Related Research Institutes

The first non-ferrous metal-related research institute in the PRC was established at the basis of an old institute established by the Kuomintang government. It was established in 1952 and specialised in metallurgy, mining, and processing. The institute later developed into the largest comprehensive non-ferrous metal- related research institute in China, the General Research Institute for Non-ferrous Metals. A series of other relevant research institutes were also established in the 1950s. They were located in Beijing, Changsha, Kunming, Shenyang and elsewhere. In the 1960s a number of research institutes were established in Chinese the hinterland. Guilin, Lanzhou, and Chengdu all had their own research institutes. To sum up, prior to the reform and opening-up, a system of research institutes which cover a wide range of research fields had been established, working in relevant research areas, providing professional consultation, and developing new equipment and technology. Following the reform and opening-up, these research institutes were transformed and affiliated to different organisations. Some became independent scientific and technological SOEs, some were affiliated to other corporations, some were given to local governments. Compared with research institutes in other industries, the non-ferrous metal industry launched the reform earlier and achieved better results. In 1995 the State Scientific and Technological Commission organised an evaluation for different research and technological development agencies. Research institutes in the non-ferrous metal industry ranked third among the 49 sectors in terms of science and technology performance and ranked first in operational performance. This transformation yielded striking outcomes. Prior to it, in 1985 the revenue of all the non-ferrous metal research institutes was 120 million yuan, while in 2008 this figure rose to 12.85 billion yuan. The total assets of all the research institutes in 1985 was 410 million yuan, while in 2008 it increased to 11.1 billion yuan. Since the reform, these institutes have taken on many more research projects and the funding for each project has also increased a great deal.

In summary, the non-ferrous metal industry could not have grown as fast as it has without the assistance of the research institutes for the following reasons. First, the research contents of these institutes are closely linked with the production chain of the non-ferrous metal industry, and there are institutes servicing every part of this chain. Second, the interaction between production and scientific research is becoming ever more intensive. This can be seen in the number of research institutes affiliated to firms. In 2007 37.12% of the large and medium non- ferrous metal firms had research activities, while 22.64% of them established research agencies. This system of research is bolstering the further promotion of the Chinese non-ferrous metal industry.

4.1.2.3 Higher Education of Non-ferrous Metal Industry

Prior to the founding of the PRC, there were few universities in China which had non-ferrous metal-related majors. In late 1951 and early 1952, the PRC government launched a grand reform in higher education in order to make revolutionary and professional universities. The first to specialise in non-ferrous metal was established in Changsha city, namely Central South Mining and Metallurgy University. This university received the relevant majors and professors from Wuhan University, Hunan University, Guangxi University and others. Two years later, another university specialising in non-ferrous metal was established in Kunming, which was followed by a third in 1958 in Ganzhou city. These three universities laid the foundation for the non-ferrous metal industry. Some small colleges were also established all over China. Most of these universities and colleges did not provide graduate-level education, let alone PhD-level education. By the end of 1983, the 10 universities affiliated to the SOE in charge of all non-ferrous metal-related matters in China had 15,108 students, among which 11 were PhDs and 374 Masters. They made great contributions to Chinese industry. For example, they provided essential materials for atomic bomb, hydrogen bomb, and satellite technology. During the Reform and Opening-up period, most of these universities expanded rapidly, admitting more students, employing more teaching staff, and offering more advanced courses. In the late 1990s, these institutions were either put under the control of the Ministry of Education or local government, and they established more majors to become comprehensive universities. They have been forming a University-Institute-Industry complex with non-ferrous metal companies and invest in laboratory construction and training sites.

In conclusion, the history of the coal mining and non-ferrous metal industries have not been immune to the greater political and economic environment of China but were part of it. The Triple Helix of the two industries were formed from their very beginning, labelled Triple Helix 1 by Etzkowitz and Leydesdorff: “In this configuration the nation state encompasses academia and industry and directs the relations between them” (2000, p.111). Although this model of Triple Helix lacks positive interaction, it did instil the idea that research and production should and could be mutual beneficial and, moreover, it sowed the seeds for future interaction by constructing channels for government, university, and industry. To some extent, the development of the mining industry’s higher education system was meant to service this industry. Consequently, the ensuing close relationship between the academic community and industry after the reform and opening-up was a natural progression.

This industry chain will be divided into the following parts, that is, prospecting, mining, processing and metallurgy. These four stages will be discussed in turn. Mining equipment manufacturing will also be included in this study as it is an indispensable part of the mining industry. Every stage of mining uses equipment, although equipment manufacturing itself does not belong to mining. By comparing these different stages, the intra-industry divergence can be uncovered.

4.2 Prospecting and Mineral Exploration

Prospecting and mineral exploration are different. Prospecting is the first stage of geological analysis of a territory. It is the physical search for minerals, fossils, precious metals, or mineral specimens, while mineral exploration refers to the process of finding ores (commercially viable concentrations of minerals) to mine. Mineral exploration is a much more intensive, organised, and professional form of mineral prospecting and, whilst it frequently uses the services of prospecting, the process of mineral exploration on the whole is much more involved.[14] As far as the total amount of cash flow to prospecting is concerned, the Chinese government has increased its investment in prospecting. From 1950 to1960, the investment in prospecting has risen dramatically. From 1961 to 1968, it decreased very fast. The following decade (1969-1979) witnessed a stable increase. The period 1980-1987 saw a second decline. During 1988-1990, the state transferred part of the sales revenue of oil and natural gas to prospecting. The corresponding figure rose, whereas this figure decreased continuously from 1991 to2005 (Ge, Xu & Ai, 2007). After 2005, China invested an increasing amount into prospecting. The year 2012 saw some 120 billion yuan invested in prospecting. The central government invested 4.58 billion yuan, local governments invested 9.7 billion yuan, the rest was social investment. The sum of 78.6 billion yuan was used for oil and gas exploration (The Yearbook of the Chinese Mining Industry, 2013).

The prospecting stage is often called a Regional Geological Survey(区域地质调查) while, according to *General Requirements for Solid Mineral Exploration of the PRC*, the mineral exploration stage can be further divided into four sub-stages, that is, preliminary-exploration (预查), general-exploration (普查), in-detail exploration (详查) and Mine Prospecting (勘探).

[14] In this thesis, when the term ‘prospecting’ is used, it might refer to the two stages as a whole, or specifically referred to the fourth sub-stage of mineral exploration, which will be introduced afterwards.

The earliest stage, regional geological survey is the systematic investigation of the geology beneath a given piece of ground for the purpose of creating a geological map or model. The aim of doing this is to maintain the geological inventory and advance the knowledge of geosciences for the benefit of the nation. In China, this stage is highly confidential. Now only government bodies and private firms which used to be part of the government can gain the legal right to participate in prospecting at this early stage. The regulation authority in China is called China Geological Survey(中国地质调查局, hereafter CGS), which is a sub-ministry level bureau under the regulation of the Ministry of Land Resources. The CGS administers several agencies. They can be attributed to a regional geological agency (the CGS has six local branches. For instance, The Centre of Geological survey in Tianjin), a professional geological survey agency (for example, Qingdao Research Institute of Marine Geology), a comprehensive research and service agency (for example, the National Geological Library), and a scientific and technological innovation support agency (for example, the Chinese Academy of Geological Science).[15] The prospecting work at this stage cannot directly yield economic benefits. It has more to do with national security. This can explain the phenomenon I observed in the Yunnan Provincial Bureau of Geological Surveys while conducting an interview. Every laptop has a sticker saying internet access is strictly prohibited. In the past China had several waves of geological surveys. Prior to the reform and opening-up, the Chinese government put a huge amount of money and manpower into drawing an accurate geological map. By 2010, the geological map with a scale of 1:1000000 had covered the whole of China. The 1:200000 scale map has also covered most of the mainland, and even the 1:50000 scale map has covered 22% of the whole land area (Wang,2013, p.61).

Shortly after the founding of the PRC, the Ministry of Geology was also established in 1952. From the first Five Year Plan to the third Five Year Plan, the Chinese

[15] China Geological Survey's website, viewed 2016/11/15, http://www.cgs.gov.cn/.

government organised large-scale prospecting activities and the outcome was striking. The prospecting investment contributed to the establishment of five coal production bases and 10 steel production bases, and a huge increase in the deposit of gold. Prospecting work during this period also paved the way for the discovery of large oilfields such as Daqing and Shengli. The distributional law of groundwater was studied, and the basic geological information which was essential for bridge building was collected as well.

During the 1980s-1990s, the Chinese government did not invest enough money in regional geological surveys. It was not until the early 21st century that regional geological surveys regained the attention of the party leaders. There is not too much state-of-the-art technology used now in China, prospectors mainly utilise traditional ways of prospecting such as combing through the countryside, often through creek beds and along ridgelines and hilltops, often on hands and knees, looking for signs of mineralisation in the outcrop.

The mineral exploration stage has four sub-stages, and successful exploration directly leads to the digging of valuable mines. The first two sub-stages link mineral exploration with a geological survey. The earliest, preliminary exploration, aims to gain rudimentary knowledge of a specific region's mining resources through a comprehensive study of the information of this region obtained from the previous geological survey, observation, and some engineering experiments. The outcome of this stage might be beneficial to the development of the local economy and might identify regions with high potential for discovering valuable mines. The ensuing stage is general exploration. A region will go through this stage only when in the preliminary exploration it has been identified as having high mining potential. The prospectors will use geological, physical, and chemical methods to prospect this region and take sand and rock samples to conduct further experiments. Compared with the preliminary exploration stage, general exploration seeks to narrow the scope of the prospective mining area, thus reducing future prospecting investment and adding more detail to the prospecting results.

The third sub-stage of mineral exploration is in-detail prospecting, or valuable mines' deposit geological survey. This work is based on the discovery of the former stages. If something unusual is recognised, which foreshadows a potential mining area, more prospectors and capital will be invested in this stage. Due to the fact that the prospecting outcome of this stage might lead to the discovery of a new mining area or the establishment of a new mine, private firms begin to actively take part although the power of state-owned prospecting agencies is still unmatched. The aim of the prospecting work at this stage is to gain information about the quantity of the deposits, the type of the mine, the geological features of this region, thereby paving the way for the next stage. The prospectors adopt various methods and skills, working systematically and getting more samples, conducting a pre-feasibility study, making comments on whether this region has developing value, demarcating further prospecting areas, and providing a general plan for future mining activities.

The last stage is mine prospecting. At this stage, prospectors work within the area which contains valuable mines. The outcome of this stage is usually a report which includes almost all the useful information for prospective mine managers: the production scale; product plan; mining method; mineral processing plan; mine construction plan etc. Most of these areas were identified in the previous stages. This part is closely linked to the ensuing mining stage which will yield economic profits, so many private firms participate in mine prospecting.

In order to prospect at this stage, one has to get the exploration rights from the government. The government tends to confer the exploration rights upon organisations which belong or are affiliated to the government. Private firms which have an apparent government origin, say, the founder of the firm used to be a government official, will be more likely to gain the rights. I would argue that this might explain the lack of innovation at the prospecting stage, because it is not the technological level but the personal network of a firm that determines whether it can get the exploration rights. To some extent, however, it is also a reflection of the embarrassing situation facing the government. The current system of prospecting in China evolved from the previous history when only governments at different levels were allowed to undertake prospecting. In fact, during the pre-reform era no private economic organisation is allowed to exist. In the 1980s, the central government launched a decentralisation reform, and local governments gained the power to make independent plans to boost local economies. Township and village enterprises (TVE) thrived thereafter. Since those TVEs cannot obtain primary materials from governments, they attempted to do mining themselves. In 1986, China had over 120,000 township and village mining companies and private mining companies (Su & Zhang, 2003). Whilst the practices of those companies were to some extent illegal, this is a clear sign that the control of government over exploration rights had loosened. Finally, in the late 1990s privately owned exploration rights became legal. The relevant legislation also confers upon individuals the right to purchase and sell exploration rights to others. The question is that becoming legal is not enough to attract private companies to undertake exploration as state-owned-enterprises still enjoy a dominant position. As a result, even though market reform has been in process for decades, the new spin-off prospecting firms cannot develop too rapidly. Sometimes it is less risky to confer the exploration rights upon someone whom the officials concerned know or are former colleagues of the officials.

Meanwhile, the successful rate of prospecting is quite low, this is the most uncertain stage, after all the prospector's work is to find something valuable from nothing, while miners' and engineers' work is different in nature from that of prospectors. This restrains the development of prospecting firms and explains why prospecting firms grow much more slowly than mining and metallurgy firms. The high sink cost and the risks accompanying prospecting give rise to the relative low innovation incentive of prospecting technicians. To make matters worse, in China exploration rights are separated from mining rights, which means it is possible that the prospector cannot extend its industry chain to the mining stage. The final product at the prospecting stage is only a potential mining area. To realise this potential, requires the valuable mines underneath this area. Without a reliable promise of the mining rights, the prospector will always face the danger of being unable to harvest its own economic benefits. Why invest a lot of money in doing R&D to improve the effectiveness of prospecting? Based on the foregoing, in the Chinese context, prospectors face a tough situation. They either waste a huge amount of capital and manpower and find nothing, or cannot obtain the rights to excavate the mining discovered by themselves.

Apart from this, the following problem is also detrimental to the development of prospecting in China. If a potential mining area is quite large, the exploration rights might be given to several prospecting teams. The rationale for doing this is that local governments have more bargaining power over the owners of small mines. If a local government has to face a mining giant, the situation will be quite different. This kind of prospecting feudalism will result in man-made division of small mines, which obstruct the utilization of economies of scale thus produce inefficiency. Each small mine owner will not be interested in purchasing advanced mining machines because large machinery is not applicable to small mines. The decrease of profits in the ensuing mining stage will in turn reduce the financial resources the prospector gained in the previous prospecting stage. Without sufficient financial support, the prospector would feel more reluctant to undertake R&D.

Policy-makers in China are also aware of these problems, and have implemented two policies to address the issues I mention. One is the encouragement of so-called 'equipped exploration' or 'assembled exploration'(整装 勘查), the other is the encouragement of so-called 'integration exploration'(整合勘查). The former policy addresses the time wasted between different stages of prospecting. I divide the prospecting stages into five sub-stages, although in fact the reality is more complicated than this, and to make matters worse, in most cases the prospector has to apply for the exploration rights for the next stage upon accomplishment of the previous stage, which is rather time-consuming and cannot keep pace with the rapidly developing Chinese economy. Equipped exploration means the prospecting team or organisation, to save time, co-ordinates with the mining firm in a region where mining prospects are quite promising. The prospecting team should make a comprehensive prospecting plan charting from the very beginning of prospecting to the final stage by taking the advice of the mining firms into consideration. Sometimes the team even needs to undertake prospecting when the mining firms have begun their mining operation. The latter policy, that is, the integration of exploration policy, is designed to solve the problem described that a number of large mining areas have been divided into numerous small mining areas. The exploration rights will not be exercised independently by different prospecting teams, but there is a central committee in charge of integrating and allocating all the prospecting resources, including human resources, technological resources, and financial resources. By doing so, the scarce resources will be utilised in a much more efficient way. These two policies have similarities and differences, both were designed to approach a specific prospecting issue. This kind of management innovation is conducive to enhance the motivation of the parties concerned prospecting technology. We need to wait and see if the two policies can live up to the decision-maker's expectations.

I now focus upon the technological innovation in this stage. By and large, the level of Chinese prospecting technology is still low and there are not enough policies to encourage the innovation, creation, diffusion, or adoption at this stage. Before continuing, I need to clarify that some type of prospecting work will accompany the development of the mine and will not stop after the mining stage. The pre-mining prospecting and in-mining prospecting use similar technologies, they only differ in accuracy and targets. In-mining prospecting will not be specifically discussed.

So, what exactly is the technological level at the prospecting stage in China? It is necessary to understand the industry chain and profiting model of prospecting in

China. In China, prospecting's upstream industry includes general purpose equipment manufacturers, prospecting equipment manufacturers, and the oil and gas industry. The first category refers mainly to machine tool makers and diesel electricity generator makers, while third category companies are included because prospecting consumes a large amount of oil and gas. Prospecting's downstream industry includes solid mineral digging and developing companies. Prospecting companies in China earn their keep mainly by selling their prospecting report to mining companies or selling their exploration rights. Because in China exploration rights are just like intellectual property rights, the best result one can get by exercising this right is the discovery of valuable mines, and due to the separation of exploration rights and mining rights, and the separation of prospecting and mining companies, prospectors are unable to appropriate the profits of their own efforts. The relatively closed prospecting community preclude the entry of new competitors, thereby leading to a low level of investment to innovation. I found that, generally speaking, technological innovation is not the most important choice to improve prospecting performance. There are some innovations at the prospecting stage but they are not likely to become the main engine of prospecting in years to come but may only complement the prospectors' work occasionally.

Primarily, Chinese scholars' understanding of the geological structure and metallogeny[16] is becoming better and better, due to the fact that China covers a large land area and has a great variety of geological conditions which provide sufficient research materials. Some of my interviewees even claimed that the academic level of Chinese scholars in this area is world class. Of course, this is not technological innovation but more of a scientific breakthrough, but it can be used to identify potential mining areas thus it is just a step away from innovation. I do not know if my interviewees exaggerated the academic level of Chinese scholars, but

16 Metallogeny is the study of the genesis and regional-to-global distribution of mineral deposits, with emphasis on their relationship in space and time to regional petrologic and tectonic features of the earth's crust.

compared with other parts of prospecting this part might represent the best aspect of the Chinese prospecting industry. As this study focuses upon technological innovation rather than pure scientific or theoretical breakthroughs, this part(metallogeny) will not be attached too much importance. Second, the digitalisation of individual tools is used by prospectors on the front line. In the past, prospectors used paper maps and pencils to draw geology maps, which is slow and inaccurate. The situation will become worse if we try to compare maps drawn by different prospectors and combine them. By using digital tools, the mapping process becomes more standardised and it is easier to analyse the data collected by prospectors from all over the country. Finally, more frontier technologies are being used at this stage. For example, the Chinese BeiDou Navigation Satellite System is helping Chinese prospectors to rely upon domestic products rather than foreign products. Other advanced equipment is also being used. This is not to say, however, that prospecting teems with innovation in China. First of all, these technologies are not decisive to the outcome, but prospectors' own ability and talent are. This is not like the mining stage in which technologies have to some extent replaced miners to become the mainstay of productivity, in prospecting stage technologies are still affiliated to its users. Moreover, the political forces separating the prospecting stage from the ensuing mining stage thus cut the link between prospecting and its economic output, consequently taking prospecting further from the commercialisation of its discovery, thus from innovation.

In 2016 the China Geological Survey published two reports which introduced around 100 geological survey technological and theoretical innovations. These innovations cover regional basic geology, mineral resource geology, environmental geology, remote sensing geology, geophysics etc. In the news conference, the Party Secretary of the China Academy of Geological Science, Wang Xiaolie stated that: “in the past hundred years, especially after 1999, China made numerous theoretical innovations and technological innovations in geology”. For the former, the theory of the gas sources condition of gas hydrate formation, the origin of birds, the porphyry Cu deposits in collisional zones, and karst dynamics are some of the representative examples. For the latter, aerogravity survey technology, multi-target zone geochemistry survey technology, the technology of coring for scientific ultra-deep drilling, 4,500-metre deep sea comprehensive survey technology are some of the representative examples. The China Geological Survey convened 21 institutes under its regulation to collect the most significant achievements in this field. In the end, 96 geological theoretical breakthroughs were chosen (China Geological Survey, 2016a), 114 relevant technologies were chosen (China Geological Survey,2016b).[17] Before the publication of these two reports, another report entitled 'A hundred achievements of the China Geological Survey' (China Geological Survey,2016c) was composed of six chapters and demonstrated 128 achievements. It systematically stated the contribution of geological survey agencies and their staffs to China. The first chapter is about how geology serves national security by gleaning basic information concerning all kinds of mines. The second chapter is about the geology survey of oceans. The third is about how the outcome of geology surveys help planners make more scientific regional blueprints. The fourth chapter is about the contribution geology surveys have made to bolster the building of a more ecology friendly civilisation. How to use geology surveys to improve disaster relief work and how to enhance scientific and technological innovation as well as international co-operation are also discussed. This report conveys the message that the China Geological Survey is endeavouring to make their outcome mature product which can be bought and sold on the market, thereby shortening the distance between geological discovery and commercialisation. Together, the three reports constitute a panorama of the prospecting industry It is still labour-intensive. Whereas technology is becoming increasingly important, the people working in this part of the industry chain have been aware of the catalytic function of commercialisation. A qualitative change, however, is impossible without the fundamental reform of the regulation institution.

[17] http://www.mlr.gov.cn/xwdt/kyxw/201611/t20161115_1421760.htm viewed on 2017-2-16.

In conclusion, in China, policies and regulations has created a man-made gap between prospecting per se and its potential commercial contribution. As I have defined innovation as the commercialisation of invention, in the Chinese context innovation will rarely occur at the prospecting stage, as for technological innovation it appears even less in prospecting stage. Besides, the innovators and the practitioners at the prospecting stage are neither the same group of people nor have bounded together as they have in the mining stage. Consequently, this separation obstructs interactions between innovators and customers, which is vital for innovation in a knowledge economy. From a systemic point of view, the relative isolation of prospecting work from other stages is the main reason responsible for the low level of technological innovation. The market mechanism has not played its role at this stage, while the interrelationship between different nodes of the whole prospecting network have not joined together to facilitate the diffusion of useful knowledge. Technology has to adopt the form of a product to fulfil its task of enhancing social welfare. The product of prospecting, however, is not physical product. What is more, the source of its profits, namely, the downstream mining companies, always suffer the fluctuating prices of mining products. All these difficulties result in an unstable foundation for long- term commitment to innovation, which might be the direct cause of underinvestment in prospecting innovation.

4.3 Mining Machine Manufacturing

The mining industry has always been capital-intensive. However, nowadays, it is becoming increasingly machine-intensive. I have witnessed many kinds of mining machines in different mines and watched carefully how they functioned. Various mines have different technical levels and use a great many kinds of mining machines. Some mines are more reliant upon machines, others count on the miners. The commentaries about Chinese domestic mining machine manufacturers, however, are almost the same across China, whether in metal mining or coal mining. Except for one or two technological breakthroughs by Chinese manufacturers, all the interviewees deride the technical ability of domestic manufacturers. There seems to be a consensus throughout the industry that machine manufacturing is weak.

In Inner Mongolia, I visited a mine belonging to the Yindu Mining Group which produces lead zinc and some silver. It is not a big mine, but can excavate and process 3,000 tons of metal on a daily basis. The Yindu Mining Group has several stockholders, one of which is a privately-owned company which has been ranked among the top 500 private companies in China. The mining technicians showed me how the mineral processing machines perform their functions. The degree of mechanisation degree is quite high and there were not many workers in the factory. The machines include a ball mill, a type of grinder used to grind and blend materials for use in mineral processing and some other processes. A ball mill works on the principle of impact and attrition. Size reduction is achieved by impact as the balls drop from near the top of the shell. I watched from outside the ball mill so I could only see the minerals being sent into the mill become smaller or broken into pieces after being sent out. The next step is to use a chemical reaction to separate the valuable minerals and the rocks and so on. Because the minerals and rocks are smashed they will have a larger reaction area which will facilitate and accelerate the chemical reaction. I also saw the container the mine used for generating the chemical reactions. As at this stage, a poisonous chemical substance is used, while the processing machine had been set at the automation mode and only workers with masks came across to supervise this process occasionally.

The technician stated that they purchase the machines, including the ball mill and the container for the chemical reaction, from a joint venture in Tianjin. The machines were designed abroad but because Chinese law stipulates that mining firms must not buy mining machines whose production process has no Chinese elements; the designer has to co-operate with a Chinese firm to establish a production plant. By and large, these machines are based on a foreign idea but made in China. The technicians also said that, compared with foreign products, machines designed and produced by Chinese firms, are cheaper but not that reliable, which means they will have bugs on a regular basis. This will slow down production and cause economic loss. Normally, machines made in China are much cheaper but can only be used for a much shorter period of time than imported machines. In order to compensate for relatively poor reliability, Chinese firms provide timely after-sales services. They often promise to send their technicians to the factory when the machines have problems within 24 hours. If this mine is their lead consumer, some engineers live and work with the miners. I visited another mine in Inner Mongolia. There the engineers introduced the excavation machine to me. Again, the degree of mechanisation is quite high. Workers do not dig up the coal themselves, they control the machines instead. The machines are also foreign designs. That coal mine is owned by Yitai Group, which ranked 227th among the top 500 Chinese companies and 18th among the biggest coal companies. It is also a private company. In Yunnan province, I went to a tin mine belonging to Yunnan Tin Group, a century-old company, and is the largest production and manufacturing base in the world for tin and the largest production centre for tin profiles, tin chemicals, and arsenic chemicals in China. It is a state-owned enterprise. The manager of the mine pointed at a giant blast furnace: "when we bought that blast furnace from Australia it was the only one of this sort in the world, even Australia itself did not own such a blast furnace." To sum up, Chinese domestic mining machine manufacturers are still in a relative disadvantageous position vis-à-vis their global counterparts. Chinese mining companies, be they state-owned or privately owned, regard domestic products as inferior to foreign products.

Category	Price	Service	Lifespan of scraper conveyor	Lifespan of Hydraulic Support	Degree of Automation
Domestic	Low	In time	5-8 million tons of coal	10-15 million tons of coal	Low
Expo	High	Weak	20-25 million	30 million tons	High

			tons of coal	of coal	

Figure2: A comparison between domestic products and imported products.

Source：http://finance.glinfo.com/13/0115/11/65651731A39B3A7F.html viewed on 2016-11-16.

The top five Chinese coal mining machinery manufacturers in 2015 are shown in the table below. Other construction machine makers such as Sany and Xugong are excluded.

Names	Revenue in millions of US dollars
Tiandi Science & Technology Co. Ltd	1,785
Shandong Energy Heavy Equipment Manufacturing Group Co. Ltd	1,120
China Coal Mining Equipment Co. Ltd	1,034
Pingmei Shenma Equipment Group Co. Ltd	932
Zhengzhou Coal Mining Machinery Group Co. Ltd	555

Table7: The top Five Chinese mining machinery manufacturers in 2015.

Source: http://mt.sohu.com/20160804/n462569724.shtml viewed on 2016-11-16.

In 2016, The United Nations Industrial Development Organization (UNIDO) issued a report on Competitive Industrial Performance (CIP). This index uses three dimensions of sub-indicators to evaluate different countries' industrial competitiveness. The three dimensions are: Capacity to produce and export manufactured goods; technological deepening and upgrading; world impact (UNIDO, 2016, p.199). Among the five most competitive are four high-income countries (Germany, Japan, the Republic of Korea, and the United States), while China ranks fifth. China's position in the ranking is attributable to its high share of global trade, although low per capita values indicate that manufacturing has the potential to grow further (Ibid, p.201). The Chinese Academy of Engineering also issues a similar report, i.e. Manufacturing

Power Development Index Report. In the latest version, China ranked fourth[18].It has four first-tier indicators, i.e. quantity, quality, structure, and sustainability.

First Tier Indicators	2012	2013	Annual Growth	2014	Annual Growth
Quantity	42.93	46.77	3.84	49.22	2.45
Quality	12.76	13.28	0.52	13.40	0.12
Structure	19.32	19.52	0.2	18.78	-0.74
Sustainability	14.48	14.46	-0.02	14.96	0.5
Overall	89.48	94.02	4.54	96.36	2.34

Table8: Changes in China's four first-tier Manufacturing Power Development Index indicators from 2012 to2014.

Source: http://www.360doc.com/content/16/0604/07/22081874_564896641.shtml viewed on 2016-11-16.

According to these two reports, it seems that China has become a manufacturing superpower. In fact, China's position in these rankings can be ascribed to quantity rather than quality. In the second report, other high-ranking countries score higher in quality than China. The preference for foreign mining machines is a vivid reflection of the inferior quality of Chinese products.

One possible explanation of this phenomenon is that history matters. Prior to the reform and opening-up era, there were several coal mining machine manufacturers. Their task was to offer services to the local coal mines. For instance, Zheng Zhou coal mining equipment factory（郑州煤机厂）main customers were the coal mines in Henan province. This led to the narrow horizon of each manufacturer, they only focused upon local needs, which was not a severe problem in the past but will have detrimental consequences in an era of globalisation. The firms which grow more

[18] http://www.cae.cn/cae/html/main/col34/2016-07/01/20160701085455818943772_1.html viewed on 2016-11-16.

rapidly under globalisation are those that can meet the requirements of different customers, especially when the industry in question is mining. As is widely known, there is a great diversity of geological structures all over the world. the ability of mining machine manufacturing firms to adapt can only be cultivated by designing and producing different kinds of machines which can be used on different occasions. Those Chinese firms are flirted (quoted Prof Martin Fransman's remarks) by the large regional market in different parts of China and, to make matters worse, they used to have ‘iron rice bowl’, because the mines in a specific region also have only one choice when they made purchasing decisions. This isolated the users and producers of the machines. The lack of user-producer interaction kills the potential communication opportunities thus blocking the opportunity for innovation. After the Reform and Opening-up, especially after the socialist market economic reform, these firms were pushed to compete in the market so they have been trying to gradually develop the capacity to compete in an environment which they are not familiar with, although the pace is slow. In consequence, Chinese mining machine manufacturers lost their market share when the global giants came to China. The current mining machine market in China is highly stratified. The largest mining companies, such as Shenhua, can purchase the most advanced machines, while most other mining companies can only select from a list of local or small manufacturing companies. As for relatively small manufacturing companies, the tough years after 2012 distracted them. For instance, Jizhong Energy Group, one of the largest coal mining companies in China, owns a small equipment manufacturing company. According to the report the company provided, it has a revenue of 1.53 billion yuan (US$245.6 million). It used to manufacture coal mining machinery, but due to the terrible condition of coal mining after 2012, it has developed several other business fields. It has begun to produce environmental protection vehicles. It has also co-operated with a German company and produced military equipment for the People's Liberation Army. The situation facing this company epitomises that of the average Chinese mining equipment manufacturer. They need to choose either to diversify or to compete with other counterpart companies not via quality but via price. Many small mining equipment manufacturing companies have merged with mining companies, but this will not make them better off as their mother companies annex them in order to become larger, not to help them promote their products. Even after the acquisition, the mother company will not promise to purchase their products. If the mother company is big enough, it will definitely prefer foreign products.

One thing worth mentioning here is that, China is good at manufacturing hydraulic support.

Figure3: Chinese made hydraulic support.

A hydraulic support is a mining support in which the load-bearing elements (pillars or props), movement, and the shifting of ceilings, protective coverings, and auxiliary units are performed by means of hydraulic devices. Its function is to create space in which a mining machine or workers can operate and perform their tasks. The strength of Chinese-made hydraulic supports is that its height is higher and can meet various kinds of geological conditions. An interviewee said that a great many foreign visitors come to China to see the operation of Chinese-made hydraulic supports.

I will say something about the policy mentioned above, namely, the encouragement to instil Chinese elements into the production process in the hope of improving Chinese firms' technological capability. Actually, this policy can be viewed as a continuation of the ‘trading market for technology’ (TMFT) policy. China implemented TMFT policy from the early 1980s to the late 1990s in the hope of simultaneously attracting more FDI and improving domestic firms’ technological capability. This policy contributed to the advancement of technology to some extent but was not effective in cultivating the endogenous technological capability of domestic firms, thus it was finally abandoned (Xia & Zhao, 2012).

In my opinion, this policy has had an adverse effect in that it failed to distinguish between two concepts - production capacity and technological capability:

> The former incorporates the resources used to produce industrial goods at given levels of efficiency and given input combinations: equipment (capital-embodied technology), labour skills (operating and managerial know-how and experience), product and input specifications, and organisational systems. Technological capability incorporates the additional and distinct resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages. (Bell & Pavitt, 1993, p.260-261).

With the assistance of foreign partners, Chinese firms could produce the machines rapidly and of good quality, but this is an improvement of production capacity alone, while the technological capability will not be automatically achieved. Just as we cannot count on frontline workers at Foxconn to acquire knowledge of the design of the iPhone, we cannot expect the production co-operators to be future product designers either. Technological capability can only be gained by taking part in the whole process of designing, merely watching or undertaking processes under the supervision of others will not do it. The policy in question, however, involves removing Chinese firms' motivation to do their own R&D. Because their foreign friends will do it, and they have to establish joint ventures to sell their products, the basic technical ability of Chinese firms will finally be eroded, and in the end the

Chinese engineers will become salesmen.[19]

In conclusion, the path-dependence of this sector, as well as improper policy, contribute to the low level of innovation. The development trend, however, is not too depressing. Liefner and Zeng (2016, p99) argue that: "Innovation processes typical of mechanical engineering, emphasizing localization and customization, ideally match with the current needs of China's rapidly growing and diversifying economy". Investment in R&D by Chinese companies has increased recently, leading companies such as Sany have appeared, the promotion of the manufacturing sector is time-consuming, and the inputs need longer to be transferred to output compared with other functions of mining.

4.4 The Mining Stage and the Mineral Processing (Dressing) [20]Stage

For most people, it seems to be common sense that all stages in Chinese mining are quite low-tech and innovation rarely occurs. This research, however, offer contrasting findings. Among all the stages of mining, variability in innovation can be seen, meaning that some stages have contributed more innovation than others. The fieldwork relating to the mineral excavation stag provides empirical evidence for the findings. Meanwhile, the ensuing stage, namely, the mineral extraction stage, also demonstrates its achievements regarding innovation. As a result, these two stages can be seen to constitute an innovation model in the Chinese mining industry.

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[19] According to Feng (2010), there are some firms whose development has been independent of TMFT advocacy. They relied upon in-house developed products from the very beginning after entering the corresponding industries, and succeeded in building sustainable competitiveness. He points out four components which form the distinctive differences in organisational learning systems between successful firms and those which have failed to build endogenous technological capability, i.e. the strategic intent, the authority over strategic resource allocation, the pattern of organisational mobilisation and learning integration, and the facilities and institutions for knowledge accumulation.

[20] In the field of extractive metallurgy and mineral processing, also known as ore processing, that is, the process of separating commercially valuable minerals from their ores. As a result, this research uses the term 'mineral processing' to refer to the stage following the mining stage.

To some extent, these two stages have a symbiotic relationship in China. Most Chinese mining firms specialise in mining and mineral processing, and all of the mining firms I have been to perform both mining and processing. By performing these two operations, the firm can enjoy an economy of scope and by their nature the two processes cannot be separated. It is not surprising that the innovation levels of the two stages are similar. In this context, their innovation levels are higher compared with other stages (mainly prospecting and metallurgy). When I recalled the comments of my interviewees concerning the divergence of innovation performance between different stages of the Chinese mining industry, the whole picture became clearer. They believed that, in the mining and mineral processing stages, China performs well, with some technological breakthroughs achieved by the Chinese. However, to say that the technological capability of Chinese mining firms is effective is wrong because mining firms in China mainly focus upon the business operation rather than doing R&D. They are adopters of innovation rather than creators of innovation. The position of the stage in the complete chain of the mining industry and the distance of its final product from commercial profit exerts a huge impact on the motivation to innovate. In other words, the closer the final product of a specific stage is to the market, the higher the motivation of R&D staff working at this stage. This is because, if the R&D achievement can be commercialised sooner, the relevant personnel can witness their commercial contribution more quickly and can gain the financial reward more quickly. This could explain the relative lack of innovation at the prospecting stage in China and the relative lucrativeness of innovation in the mining and processing stages. The final product of processing[21] is less pure, which means the same amount of the final product contains more valuable minerals, be it coal or non-ferrous metal, than the final product of metallurgy. Consequently, the final product of the processing stage is sold more easily, while as

21 The final product of mining is the input of processing and just as I mentioned before, the final product of mining will not be put into outside market, to the contrary it still inside one mining firm, so only the final product of processing will be discussed here.

the final product of metallurgy is purer the market needs are less if we take the industrial structure of China into consideration. More advanced industries need purer metals or coals, but as China is still a country focused upon the lower end of the value chain, advanced industry is not that important or the number and the output value is not that significant. Based on the foregoing, we must conclude that the mining firms' final product or the processing stage's final product has more potential for commercialisation, thereby creating more incentives for innovation.

This explanation for the phenomenon that relatively more innovations appear at the mining stage will be discussed later. For now, the discoveries regarding mining and processing stage will be fully elaborated.

These two stages constitute the major part of the whole mining industry and my fieldwork because they are exactly what most Chinese mining firms are engaged in, and because of this they are also the main research topic for most scholars in universities and research institutes. Scholars in Central South University,[22] Kunming University of Science and Technology,[23] China University of Mining and Technology[24] were interviewed, and mining firms such as Hunan Coal Mining Group[25],Suancigou Coal mine of Yitai Group[26],Jingmei Group[27], Yindu Mining Group[28],Yunnan Tin Group[29]

[22] It is located at Hunan Province, central China and good at metallurgy, one of 985 program university.985 program universities are the top universities in China, this program was established at the 100th anniversary of Peking University, aimed at building world first tier universities for China.

[23] It is located at southwest of China and is good at metal processing and metallurgy

[24] It is located at Beijing , the best coal mining university in China.

[25] Hunan Province, central China.

[26] Inner Mongolia, north China.

[27] In Beijing.

[28] East of Inner Mongolia.

[29] Yunnan Province, Southwest of China.

Jizhong Energy Group[30] and so on and so forth were visited. These organisations scattered around China have their own strengths and weaknesses.

Interviewees were asked the following questions: What role does technology play in your firms? Do you have an R&D department? What proportion of your profits do you invest in R&D? They were also asked to show the patents they applied for and other technological breakthroughs they achieved in the past. Apart from this, I also went to their factories to see exactly how the machines operate and I hope that, having watched this process carefully, I understand and envision the possible directions of innovation and better comprehend the functions of innovation performed in production processes. I even went underneath the ground once in Suancigou coal mine to experience the daily work of an average coal miner. I will now map a rudimentary picture of the work being done in Chinese mining firms. The experiences of visiting different coal mines will be referred to in order to depict the excavation stage and the experience of visiting a lead(Pb) mine and a zinc(Zn) mine will be drawn upon to illustrate the extraction stage.

Although my father works for a coal mining group, I had never been into a coal mine prior to my visit to Suancigou in Ordos, Inner Mongolia. The guide asked me to put on an outfit before going down. This mine is privately owned. The popular perception of a privately-owned mine is often very negative. The typical image is of miners wearing dirty clothes doing strenuous work under the dim light of a bulb. But much to my surprise, the mine I visited is very advanced technologically and according to my interviewee's narrative the social welfare of the firm matches that of a large SOE. The mine owner has done charity work and has been reported on by the Chinese media. This is because this private company is among the largest in China. As for those below average, the working conditions are still unpromising and they will

[30] Hebei Province, north China.

not let visitors into their mines. The degree of mechanisation in Suancigou is quite high, most of the mining work is being done by machines.

After donning the clothes and being given some emergency equipment, one worker (who has a bachelor's degree) led me to the entrance of the mine and then we got into a jeep and were taken to the operation face of the mine. The space in the mine was quite roomy, and the air was not teeming with coal dust. After about five minutes' drive, we reached our destination. The first thing I saw there was a line of spare machines. As the main operation of the excavation process is done by machines, it is imperative that the mine have some spare machines in case of machine breakdown. Then we walked to the operation face of the mine. Much to my surprise again, I did not witness a large number of miners. Instead, I just saw a machine and a few miners who were resting. The workers told me that, because the machines are not in operation, visitors were allowed to enter the mine for at that time it is safer. A worker introduced the machine. He majored in mining so he is quite knowledgeable about the mining machine. He shed light on the function of each component. Thanks to his introduction, I could imagine the situation. By and large, the work of the miners was easy and safe. Prior to being sent into the mine, they were required to go through a training course and the content of the course was about how to control the machine. For this group of workers, the expertise is not necessary, as is a university education. Most of the workers of this sort are local residents. Thus, the firm has contributed to the improvement of the well-being of the local people. As regards the minters' salaries, it is much higher than that of other jobs in the region. Besides, there are technicians who repair or service the machines, most of which are university graduates. It took us around an hour to finish this quasi-trip. The guide also led me to the coal mine's processing machine but as he was not in charge he sometimes could not provide clear instructions.

To sum up, the visit to Suancigou coal mine changed my perception of coal mines in China, especially regarding the typical image of a privately-owned coal mine. One explanation is that the different level of technology intensity is not determined by the type of ownership (State-owned versus privately owned) but by the size and age of the mine. The new and large mines tend to use more state-of-the-art technology, while older or smaller mines either have heavy social burdens or fall short of money to purchase the technology to replace people. As a result, current policies implemented by the Chinese government to encourage the merger and acquisition between large Chinese coal mines and small coal mines (or even coal pits) does make sense. The question, as far as technological innovation is concerned, however, is the same as in other industries. Given the increasing adoption of technology or technology-intensive equipment, will the technological capability of Chinese machinery manufacturers be improved accordingly? I am not going to argue that there is no innovation at this stage. On the contrary, I will offer several examples later in this thesis. I came to know this type of innovation from conducting two interviews, both with individuals with PhD degrees. One is a PhD candidate of China University of Mining and Technology, the other is the director of the Technology Centre of Jingmei Group. In short, this visit furnished a vivid picture of what is being done in one of the most advanced coal mines in China.

The visit to Yindu Mining Group, a lead and zinc mine, at Chifeng city in Inner Mongolia, was earlier than the trip to Suancigou. But, the main reason for my visit is mineral processing rather than mineral excavation, I decided to introduce this trip after Suancigou.

As at Suancigou, Yindu Mining Group is also located far from an urban area and the mineral processing technology used by Yindu is also quite advanced. I did not watch the mining stage, I just came across the original ore pit in which the final product was stored and awaited processing. A technician gave a brief introduction to the processing operation. It is divided into two parts, the physical processing stage and the chemical processing stage. It is obvious that the first stage is about using laws of physics to process the ores and the second is about using chemical methods to undertake processing. The mechanism here is that, by using a physical approach, the ores will be smashed, so that they do not remain big rocks but become powder. There are still many impurities in this powder, therefore, it has to go through chemical reactions. During my trip, I watched the whole process and as this is my first time in a mineral processing factory, I asked lots of questions to make sure I could understand the principle of the machines. This tour, together with the first tour, helped me to link the mining stage with the processing stage. In the Chinese context, mining and processing are often combined and called Cai Xuan, Cai' means excavation (Cai Kuang) and 'Xuan' means processing (Xuan Kuang). Generally speaking, the mining stage solves the problem of moving the mines from underneath the ground to the surface, while processing removes the impurities. Moreover, taking Yindu as an example, during the mining stage the engineers need to think about how to facilitate the ensuing processing stage. Using a football metaphor, the mining stage is like midfielders whose main task is to pass the ball to the striker while the processing stage is reminiscent of striker's purpose. Consequently, any mine design has to take the two stages into consideration. Actually, the mining stage itself includes some type of processing. In Yindu, the ores got from the mining stage will be put into a machine which separates the ores according to the diameter of the ore rock. The bigger pieces will be sent through a smashing process and the smaller will go directly to the next stage. When the diameters of the ore rocks are small enough, they will be conveyed to the chemical processing stage. A ball mill will further smash the ores into powder so as to increase the efficiency of the incoming chemical reaction. The whole factory is quite labour-saving and I did not find many workers in it. The factory environment is also better than expected and, as temporary visitors, we were not required to wear masks. I only found factory workers in masks during the later stage of physical processing. This is because, during this stage the danger of breathing in dust is high. The technician told me that the processing machine was made by a Joint Venture in Tianjin, but it is designed by a foreign firm. The engineers in Yindu made some incremental innovations, such as changing the procedure of the machine to make it more suitable to the local surroundings. Technological innovation is important to the firm but the firm itself does not focus upon it; they ask the manufacturer to do it. What the firm could do to augment its profit is some kind of organisational innovation. Apart from that, the firms could also innovate by participating in some parts of the processing stage. For instance, Yindu's technicians found the chemical reaction designed by a famous scholar did not work well. They conducted experiments themselves and finally found a better prescription and persuaded the scholar. More often than not, processing firms can only make this kind of marginal and incremental innovation.

The final product of the processing stage is also the final product of the mining, which can be sold to the market, sometimes to an end user, sometimes to a metallurgy factory. In the past decade, as the profits from mining are very high, lots of people have entered this industry. The low entry barrier results in over-production and sharp contrasts in the technology level of different mining firms.

Except for the trips I took to the mines, I also interviewed a number of scholars who specialize in mining and processing. I will not go into details of the interviews. My general impression of the interactions between scholars and workers in the production line is that, unlike the relationships between prospecting scholars and prospectors, mining or processing scholars and miners in production units have close links with each other. In Triple Helix terminology, two of the three helices interlink with each other, creating space for the so-called endless transition. In this context, ‘transition’ means the change caused by innovation. Meanwhile, the other helix, namely, the government, is not absent since it contributes to the formation of the links between companies and universities. First, some examples will be used to illustrate the innovations at the mining stage, and then the interactions between scholars and mining firms will be further discussed.

One of the examples is called the longwall top coal caving(LTCC) method. The picture below is a Chinese mining machine. It is produced by the China Coal Zhangjiakou Coal Mining Machinery Co. Ltd. (中煤张家口煤矿机械有限责任公司). The picture appears in a brochure published by the firm to promote itself in a conference in Australia. The machine is an example of top coal caving equipment. There is also a paragraph in the brochure which introduces what longwall top coal caving is.

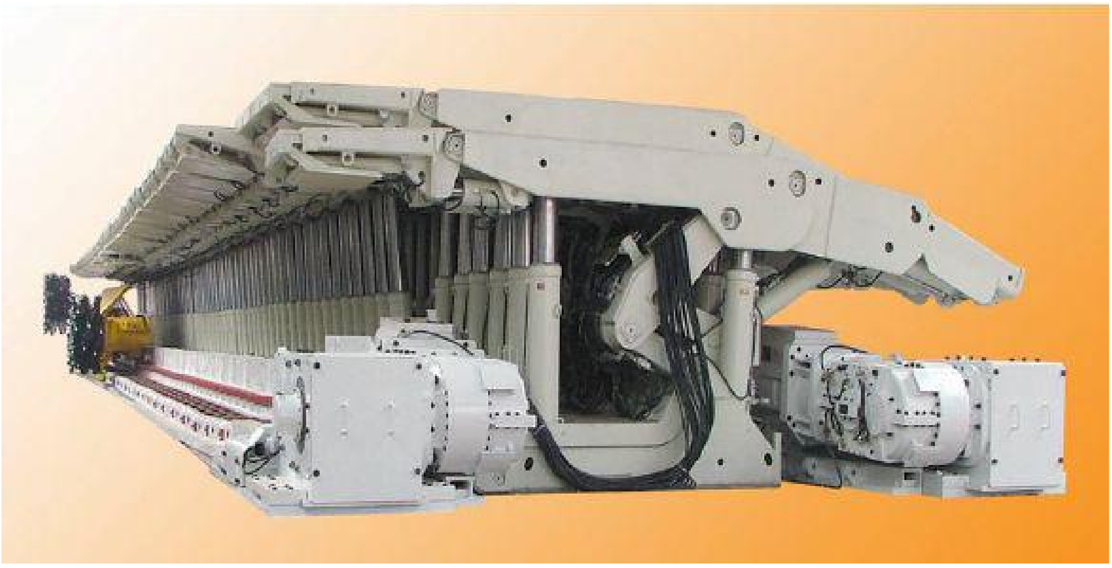

Figure4：A long top coal caving machine.

Longwall top coal caving is a special type of longwall mining applicable to very thick seams (greater than 4.5m) where good quality coal is left because conventional longwall equipment has not yet been designed to operate successfully beyond around a mining height of 5m. It enables increased recovery for an incremental additional cost.[31]

[31] http://undergroundcoal.com.au/fundamentals/07_caving.aspx viewed on 2016-11-17.

The method originated in Europe but has been developed in China in more recent years and is used there extensively and successfully. In the late 1940s and early 1950s, LTTC was used to extract thick coal seams in the former Soviet Union, France, and the former Yugoslavia (Wang et al, 2015). Given the progress of hydraulic support technology, fully mechanised top-coal caving technology was improved and successfully applied in some countries. In the late 1980s, top-coal caving technology was not widely applied and its potential was not fully achieved due to competition from other energy industries, changes in social and political systems, and the difficulties associated with its application in difficult geological conditions. Until 1992, fully mechanised top-coal caving faces had been outlawed in all countries, with the last site being in Russia. By that time, China was the only country using the LTCC mining method to extract coal from thick coal seams (Wang, 2009). In recent years, with the development of LTCC mining technology in China, the technology and equipment is beginning to be introduced in other countries, such as Australia, and is successfully used in underground coal mines. So, what exactly is LTCC?

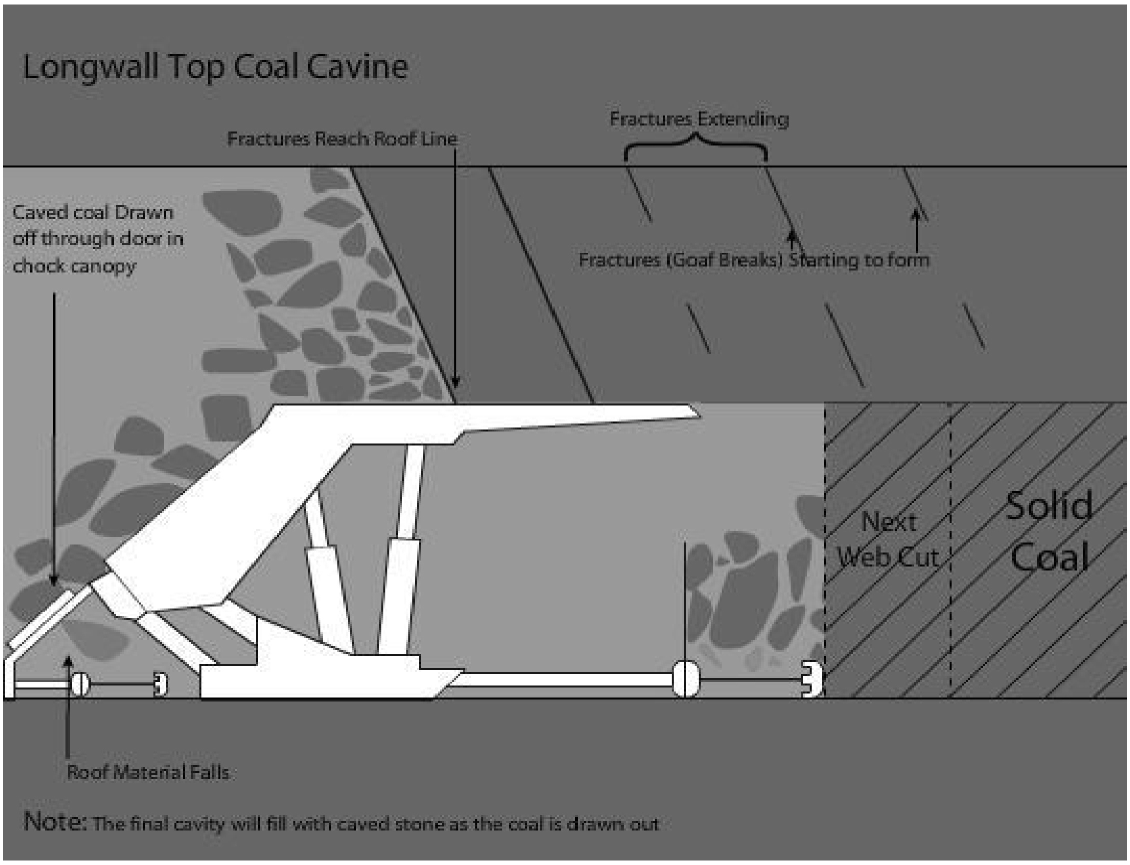

Figure5： Diagrammatic view of the principle of longwall top coal caving

Source: http://undergroundcoal.com.au/fundamentals/07_caving.aspx viewed on 2016-11-17.

The lower section of the seam is cut by a conventional longwall set-up, except that the longwall supports have a longer rear canopy extending past the base into the goaf[32]. The extended canopies have a sliding door fitted into them.

An additional armoured force conveyor (AFC) is attached to the rear of the chocks and runs directly below the canopy openings. As the face moves forward, the coal left above the section cut by the machine falls onto the extended canopies, providing the goaf is caving normally. The sliding doors in the canopies are sequentially opened, and the coal falls through onto the rear mounted AFC. The main-gate stage loader is extended beyond the face conveyor to enable the rear-mounted AFC to discharge coal directly onto it and carry coal to the main-gate conveyor system.

What China is really good at, according to my interviewees, is not the manufacturing of the machine but the way in which the machine is used. The Chinese top coal caving method can be used in a variety of circumstances, such as in a mine which has high intensity of gas, or a mine which has a very complicated geological structure. To some extent, this is a kind of process innovation rather than a product innovation.

China is also good at other mechanical mining methods for thick coal seams, i.e. a method of fully mechanised mining with a large mining height. In a conventional fully

32 Also called gob. *Mining.* waste or barren material. http://www.dictionary.com/browse/gob viewed on 2017-7-19.

mechanised top-coal caving longwall face, the coal cutting height is normally 3.0 – 3.5 m. Based on the rule of a cutting to caving ratio of 1:3, the conventional top-coal caving height is 910.5 m. In other words, the maximum thickness of coal extraction is 12 – 14 m (3+9 – 3.5+10.5). In terms of ultra-thick coal seams with thicknesses greater than 14 m, if the cutting height remains as 3.0 – 3.5 m, there will be many problems. For instance, the cutting to caving ratio will be too low (1:4.7 if the cutting height is 3.5 metre in a 20-metre-thick coal seam). Thus, it is difficult to cave top coals, and the coal recovery will be low. At the same time, the increase of coal production will result in the increase of gas emission and the difficulties in removing gas due to a limited cross-section area at the coal face (Wang et al, 2015). To deal with this, the China Coal Technology & Engineering Group, Datong Coal Mine Group, and 15 other organisations in China launched a significant project to develop coal mining technologies and equipment for coal seams with thicknesses greater than 14 m. After the completion of the project, a coal extraction method was developed for top-coal caving with a large mining height, as well as a ground control theory for ultra-thick coal seams. In addition, mining technology for top-coal caving with a large mining height, the ground support technology for roadways in coal seams with a large cross-section, and the prevention and control technology for gas and fire hazards were developed and applied. Furthermore, a hydraulic support with a mining height of 5.2 m, a shearer with high reliability, and auxiliary equipment were developed and manufactured. Practical application of the technologies and equipment was successfully completed at the No. 8105 coal face in the Tashan coal mine, China. Few other countries have achieved such a technological breakthrough. Furthermore, Datong is not the only case in point in China. In addition to the Tashan mine in Datong, currently, technologies and equipment for ultra-thick coal seam have been used in 32 coal mines in China, including 13 mining areas such as Datong, Pingshuo, Shengdong, Xinjiang, covering eight provinces or autonomous regions in China, such as Shanxi, Inner Mongolia, Xinjiang, Shaanxi, Shandong, Gansu, Anhui, and Liaoning.

Compared with the prospecting and manufacturing stages, the mining and mineral processing stages are relatively innovative. How do we explain this divergence of innovation performance? I would conclude by stating that the dynamics of systems of innovation at various stages are different, as are the Triple Helix in operation at different stages. Based on the literature review, I mainly utilise a System of Innovation and Triple Helix to organise this research. The former theory places firms at the core position of the whole system, whereas the latter focuses upon the role played by universities in knowledge production. According to my fieldwork, mining machinery manufacturers account for the most innovations, other users of this innovation system do not make significant contributions. Meanwhile, universities and academic institutions are prime contributors of the innovations occurring at the mining and mineral processing stages. As a result, the System of Innovation approach will be more useful when used to study the innovations of manufacturing firms and the Triple Helix approach can be used to explain the higher innovation level of the mining and processing stages. The nature of the innovation activities and the ecosystem of different stages are different. This contrast might foresee ways of improving the existing theory and also remind me of the rationale I might adopt to organise my research.

Based on the foregoing, I would argue that more innovations have been created in at the mining and processing stages because we find more interaction between the Triple Helix at these two stages. On the contrary, as the firms which specialise in machinery manufacturing do not co-operate intensively with other components of the innovation system in which they are involved, this leads to their relative poor innovation performance. More specifically, one can find numerous laws in China which encourage the co-operation of mines with universities and academic institutions. This is a vivid positive example of the Triple Helix. All three parts are actively engaged in this interaction. Another difference worth pointing out is that the technological innovations at the mining and processing stages are more like process innovation, whereas those at the equipment manufacturing stage are more like product innovation. The former entails less physical asset input, thus might be cheaper and less capital intensive. The latter takes a longer time to be fulfilled, so the current situation is also subject to rapid transition. More interestingly, the centrally planned economy's historical legacy still lingers on. In the past, China copied the Soviet model to establish a higher education system which characterized many revolutionary and specialist universities (又 红 又 专), which have seamless relationships with mines, thus pave the way for further and deeper co-ordination among the same actors in a novel context ,i.e. the socialist market economy. Unlike its western counterpart, the Chinese higher education system per se has an endogenous impulse to extend its network to reach the production unit, namely the mines. To some extent, this kind of path-dependence explains the eagerness of universities and mines to be business partners and the effectiveness of the policy. When it comes to manufacturing firms, historically, the equipment once used in the mining industry could be bought from either the Soviet Union or Western countries, thereby reducing the incentive to innovate domestically. Consequently, interactions between manufacturing firms and academic institutes were looser. After the establishment of a socialist market economy, no actors involved in this field were ready to construct a new bridge to the outside world. In conclusion, the finding of this research demonstrates that history matters. The situation formed during the inchoate stage of the Sectoral System of Innovation in the Chinese mining industry still exerts its influence nowadays. The old policies helped to shape this System of Innovation, and the old structure of the system will wield its contemporary influence though probably in a new form. What was once thought to be a hindrance to innovation could accelerate it when the macro context changes.

The macro economy has always had an impact on the development of each industry, and mining industry is no exception. In 2015 a large proportion of Chinese mining firms claimed heavy losses. It is reported that 50% of the listed Chinese coal companies were in deficit. This economic downturn might serve future purposes as a sieve to select which firms could survive and what approach they adopt. Some positive aspects, at least potential positive aspects, have been found. The number of coal companies reduced while the proportion of large companies increased. The mines with production capacity over 1.2 million tons account for 68% of the total production capacity. This industry's trend towards centralisation trend is becoming clear. The top four producers produced 868 million tons of coal, representing 23.5% of national production. The corresponding figure for the top eight producers is 35.5 %. The number of producers whose production capacity is over 100 million tons is nine. The contribution rate of science and technology during the 12th Five Year Plan is 49%, 10% higher than that during the 11th Five Year Plan. The non-ferrous metal industry is going through a similar process. With the closure of old mines and the opening of new mines, the part played by technological innovation is sure to be larger. The new mining giants are also more eager to invest in R&D. Some companies have begun to 'walk out' and compete with their global counterparts. These strategic actions need time to bear fruit. The firms devoting more to R&D will excel in the long run, but might face big challenges in the short term. This is exactly where the government could play a pivotal role. According to China Statistical Yearbook on Science and Technology, in 2015 alone the state-owned and collectively-owned mining companies employed some 956,000 technical staff, which is large proportion. Whether their input can be transferred to effective output remains to be seen.

Based on the history study and a summary of the different stages of mining, we may draw a brief conclusion here. The divergence of innovation performance between mining companies and equipment companies can be explained by path-dependence. To be more specific, historically, mining companies in China have developed close relationship with universities and research institutes. As a consequence, this kind of co-operation helps mining companies improve their innovation performance. By contrast, the innovation capability of equipment companies was handicapped by their loose interaction with the academic community.

5. Case Studies

There are several successful innovation stories in Chinese mining, occurring throughout the industry chain and across China. Each case has its own features. By contemplating such narratives, it is possible that the underlying laws which make each unique and valuable can be discerned.

In this section, three case studies will be provided. The System of Innovation, the Triple Helix, and Innovation Ecosystem frameworks will be referred to. This section aims to demonstrate the process through which innovations in the mining industry occur and are diffused. The theories mentioned in this research will be tested in the real world. As we have seen, these approaches do not contradict each other, nor do they substitute for one another. In fact, they complement each other by explaining the same case. Their cumulative effect can help to make this story more complete and thereby contributing to a better understanding of innovations in the Chinese mining industry.

Here is the founding of this chapter:The divergence of innovation performance across the different stages of mining identified by the former chapter is informed by two factors. First, the distance between final products and market or commercialisation, and second, the intensity of interaction between the mining company (including prospecting company and equipment manufacturer) and the university or research institute. To be more specific, the closer the distance and the higher the intensity of the interaction, the better the innovation performance. If one of the two factors do not appear, it is possible that this company's innovation performance is not desirable.

The System of Innovation approach entails that the observer focuses upon the central role of firms in innovation without ignoring other participants. Therefore, all the case studies will pay due attention to mining firms, and try to depict the complicated network through which firms get the assistance and resources they need. The components and the relationships which bind them will be discussed. As for the Triple Helix approach, the case study will try to describe the role taken by universities, research institutes, governments, and mining firms. These players are influential in innovation. To some extent, their behaviour shapes the outlook of the System of Innovation. The operation of this system and its outcome, namely, innovation, cannot be fully understood if insufficient light is shed upon major players' interactions. Regarding the Innovation Ecosystem, it attaches importance to the dynamics of the system rather than the structure of the system. By displaying what is going on in this system, it will not be static. Meanwhile, the ecosystem approach focuses more upon the functional provision of a system, rather than focusing upon its physical setting. As a result, in the case study the kind of functions the system in question provides in order to encourage innovative activities will be elaborated. The three systemic approaches lay the foundation for further discussion. At the end of this section, the fruits of the three approaches will be discussed, while the differences between the three case studies will be analysed by using the three approaches. The case studies seek to flesh out relatively abstract theoretical analysis, and draw a more vivid and detailed picture of the Chinese mining industry.

The chapter contains three case studies. The first is about a regional industry. The aim is to clearly depict the role of governments in local development and innovation. Government actions in this case will serve as an epitome of all governments at whatever level in China. The second case looks at an SOE in mining, and the concrete innovation effort of a firm will be introduced. The last case study is about a machinery firm, looking at its technological achievements. These three quite different cases were chosen in order to increase the validity of this research and to cover as wide a field as possible within the limited space. These cases are also useful as they provide platforms for NSI, TH, and the Innovation Ecosystem. In a nutshell, the diversity of the Chinese mining industry and the System of Innovation can be partially demonstrated by the cases presented here. Apart from that, the functions of each player of the System of Innovation and the way in which they perform their functions will be illustrated.

5.1 The semi-coke industry in Yulin City

Semi-coke is also called Lan Tan (兰炭), which literally means blue carbon in Chinese. It got the name 'Lan Tan' because, in the 1980s, the locals in Yulin city found that, after being burned, this kind of carbon burns blue. The name is more popular in the Chinese media, as local people in Yulin prefer this name and Yulin has become the largest production base for Lan Tan, although its scientific name is 'semi-coke'. In this research, the more formal name will be used, but in most cases in China (even at some academic conferences), 'Lan Tan' is used.

This case was chosen because of the following reasons. Above all, the case is a perfect choice to illustrate the basic logics of System of Innovation, the Triple Helix, and the Innovation Ecosystem. It also provides a platform to present the fundamental assumptions of these three theories. For the System of Innovation, as we have seen, the mining industry used to be subjected to intense state regulation and control. It has national features, and the mining industry is quite unique compared with other industries, be it manufacturing or services, thus the Sectoral System of Innovation can be used to analyse it. One unique feature of Yulin's semi-coke case is that it also has obvious regional features as the semi-coke industry is mainly located in Yulin city, so the System of Innovation theory at different levels can be applied. For the Triple Helix framework, this case also offers an exemplary chance to put the theory into practice. The government of Yulin, local semi-coke firms, universities, and research institutes take part in this industry, each of them playing a tailored role in this Triple Helix model. This kind of interaction and co-operation contributes to a great many innovations in this industry. These actions will be identified and described in greater detail later. As regards the innovation ecosystem, the unique symbiosis between the local semi-coke firms and their technology co-operator, namely universities and research institutes, the dynamic evolution of the relationship between governments, academic organisations and business, the functions each part performs, all these phenomena are similar to an ecosystem.

Second, I did an internship in the Municipal Development and Reform Commission (MDRC), thus I have prior knowledge of the semi-coke industry in Yulin and have established personal contact with officials there. One special feature of the Yulin case is that, after the market reform launched in the 1990s, generally speaking, coal mining has gone through a deregulation process. The government still holds the right to approve new mines and set production quotas, but seldom do they engage in the production process. While in Yulin's case the local governments (both municipal and county) act like co-ordinators, they help local firms which are weak in technological capabilities to establish contact with universities and research institutes which are far from production sites but strong in technology. The active involvement of governments in innovation and the relatively successful experience is helpful in broadening our understanding of the role governments should and could play well. The way through which governments participate in the local semi-coke industry will be brought to light.

5.1.1 Basic Information about Yulin and semi-coke

As Yulin city is not world renowned and most people are not familiar with semi-coke, some background information will be given before discussing this case.

Yulin (Chinese: 榆林; pinyin: Yúlín) is a prefecture-level city in the Shanbei (north of Shaanxi) region of Shaanxi province, China. It borders Inner Mongolia to the north, Shanxi to the east, and Ningxia to the west. It has an administrative area of 43,578 km² (16,826 square miles) and a population of 3,380,000.

Yulin used to be a very poor city. One of its local residents was Li Zicheng (1606-1645), a rebel leader who established the Shun Dynasty and overthrew the Ming Dynasty.

He became a rebel leader because his hometown was so poor that he would have starved to death otherwise. In ancient China, Yulin was always a border city, the Great Wall in different dynasties passed through Yulin. It is a dry city and its neighbouring regions are all desert or desert steppe. The city to its south is Yan'an, which was the centre of the Chinese Communist revolution from 1936 to 1948.

Thanks to the discovery of a large coalfield, Yulin's economy began to take off around 2000. Its GDP grew at a staggering speed, and together with Ordos, it became nationally famous for its unparalleled development. In 2000 Yulin's GDP was only approximately 10 billion yuan (about US$1.21 billion). By 2010, its GDP had increased to about 170 billion yuan (about US$25 billion), 17 times what it was in 2000. This can be attributed to the unprecedented development of the coal industry.

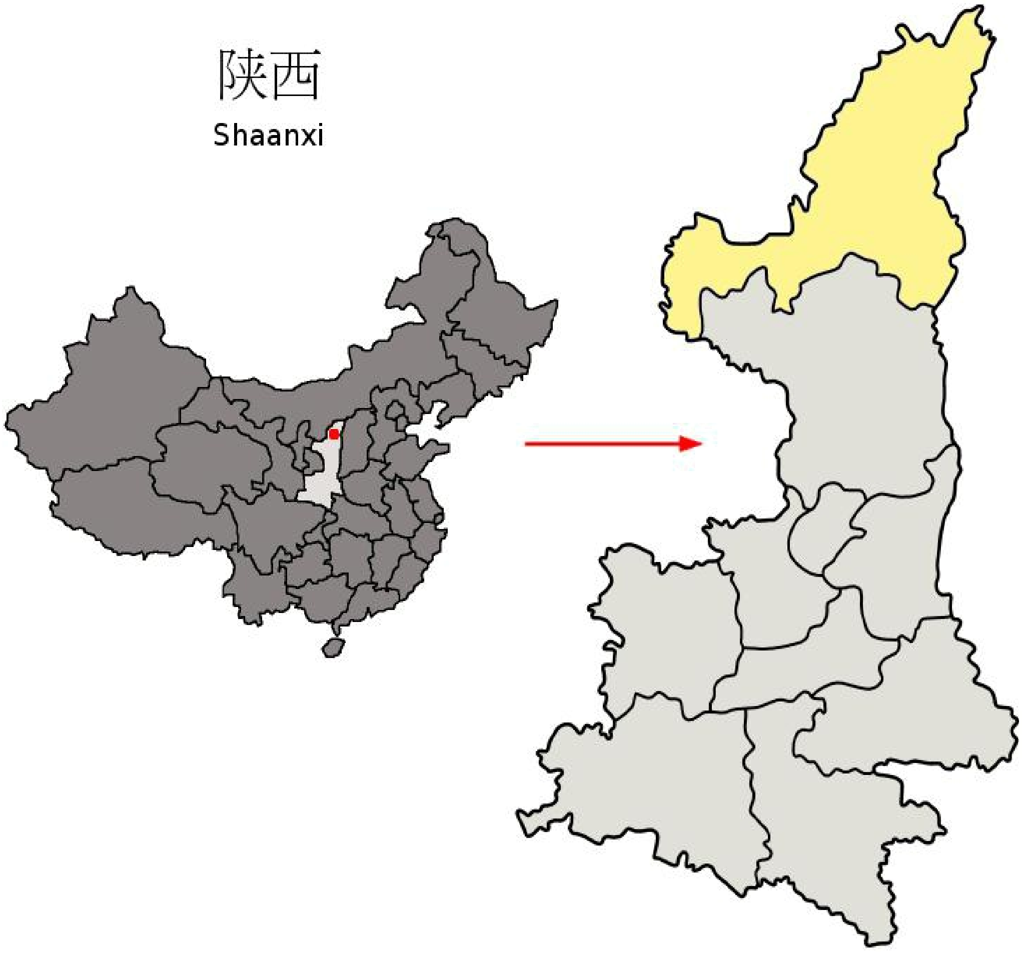

Figure 6: The location of Shaanxi and Yulin

As a consequence, when the Chinese coal industry faces severe problems so does Yulin's economy. The turning point occurred in 2012. I happened to be in Yulin in 2012. The annual GDP growth rate of Yulin in 2011 was 15%, while the same figure for 2012 was 12%. The figure then began to plummet, and the figures for 2013, 2014 and 2015 were 8.8% ,9.0%, and 4.3% respectively.[33] Yulin's mine owners used to be famous (or infamous) for spending money like water. They purchased lots of real estate properties in Beijing as well as Yulin and contributed to rocketing house prices. As a remote county of Yulin, Shenmu County teemed with millionaires. Before going to Yulin, I heard that being in Shenmu County is like watching a car exhibition free of charge. You see numerous BMWs or Land Rovers on the roads. All these economic achievements, however, are rather fragile due to the fact that the 'golden decade' of coal was the driving force behind this miracle. When the price of coal stopped rising and began to drop, Yulin's coal industry faced a huge challenge and so would Yulin's economy. In 2016 during my second trip to Yulin, I also visited Shenmu County. The relatively depressing atmosphere could be felt and it is reported that lots of rich people in Yulin have gone bankrupt.

This trend was becoming obvious in 2012 while I was an intern in Yulin. The year 2015 was the most miserable year in the past two decades. But Yulin was not alone. Most resource-rich cities, especially those whose cornerstone industry is coal, all suffered a harsh year in 2015. In fact, in 2012 the municipal DRC officials organised a series of conferences. Their themes were all linked with making diagnoses of Yulin's economy and searching for new sources of development dynamics. In 2012 Yulin's economy performed quite badly. The once fastest developing city in Shaanxi became the last but one place on the GDP growth table. To make matters worse, from 2013 to 2015 this ranking remained unchanged. Although Yulin was still the second largest economy in Shaanxi province and ranked first in terms of GDP per capita, the difficulties it faces are hard to overestimate.

[33] http://www.yl.gov.cn/site/1/html/0/5/7/38421.htm viewed on 2016-11-28.

Based on the aforementioned situation in Yulin, one remedy the people of Yulin sought was innovation, more specifically, through the development of the semi-coke industry. This strategy has attracted the attention of the Mayor and the Party Secretary. Even some high-ranking officials in the central government have been aware of the importance of semi-coke for Yulin and for the country. This is because the physical and chemical properties of the coal in Yulin make it the perfect raw material for producing semi-coke and other related products.

According to Merriam-Webster, semi coke is: "the solid residue obtained by carbonization especially of coal at a relatively low temperature (as below 700 ° C) that is in general softer and more friable than coke from carbonization at higher temperatures, that gives a hot smokeless fire, and that can be used as a domestic fuel."[34]According to Wiktionary, semi-coke is: "Any of a range of products intermediate in composition and consistency between coke and pitch formed by the incomplete carbonization of coal."[35] In order to obtain semi-coke, the coal needs to go through carbonization, which is: "the term for the conversion of an organic substance into carbon or a carbon-containing residue through pyrolysis or destructive distillation. It is often used in organic chemistry with reference to the generation of coal gas and coal tar from raw coal."[36] During this process, coal will be put into a hermetically sealed container, and heated without air. Compared with ordinary distillation, it entails a higher temperature. This process ends with three forms of substance, liquid, solid and gas, among which the liquid is mainly coal tar and the solid is semi-coke. In other words, semi-coke can be obtained by processing coals, and it is one of the three end products of the coal carbonization process. The reason why Yulin's coal is perfect raw material for producing semi-coke is that it

34 http://www.merriam-webster.com/dictionary/semicoke viewed on 2016-1-28.

35 https://en.wiktionary.org/wiki/semicoke#English viewed on 2016-1-28.

36 https://en.wikipedia.org/wiki/Carbonization viewed on 2016-11-28.

contains more coal tar, thus making the carbonisation process more profitable. Strictly speaking, all the coal can be carbonised; the question is not a technological one but an economic one. During an interview with a coal mine manager in Hebei Province, he said that a government official in another province forced the local coal mines to produce semi-coke, but the coal in that province does not contain enough coal tar, and this project did not yield enough benefits. The logic of bolstering local firms to engage in semi-coke processing is to make the best use of Yulin's coal's advantage and add more value to the final products. This can help local firms augment their profits and broaden their marketing channels.

Another scientific concept in relation to semi-coke is pyrogenation or pyrolysis (热解). Pyrolysis is the thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen). It involves a simultaneous change of chemical composition and a physical phase, and is irreversible.[37] The pyrolysis of coals can be traced back to the 18th century. At that time, people wanted to get household fuel through the pyrolysis of coals. Afterwards, they learned how to get raw materials for chemical engineering and fuels for engines by processing coal tar, a product of the pyrolysis of coals. The development of pyrolysis of coals has experiences the changing fortunes throughout history. Shortly after the Second World War, this technology enjoyed high speeds of growth, but after the 1960s, as the petrochemical industry began to take off, the status of coal pyrolysis dropped accordingly. Two reasons explain this, that is, the low price of crude oil and the relative shortage of coal in the rest of the world. After the 1990s, the pyrolysis of coal saw a resurgence due to the soaring price of crude oil. Scholars made some breakthroughs in their laboratories and basic research in this area was pushed forward. The question is that only in China did those academic achievements find a platform to be put into industrial application. In almost all other countries, they

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[37] https://en.wikipedia.org/wiki/Pyrolysis viewed on 2016-12-6.

never left the university laboratory[38]. It is through the middle or low temperature pyrolysis of coals that semi-coke can be obtained. To sum up, the pyrolysis of coals is not a new scientific discovery but the turn to coal pyrolysis in the hope of obtaining semi-coke and realise industrial application is unique in China.

5.1.2 A brief history of the semi-coke industry in Yulin[39]

What is unique in Yulin's case is the intensive involvement of government in local development. Moreover, this kind of involvement is not direct control or bringing order etc. By and large, Yulin's municipal government orchestrated the co-ordination of local firms, state-owned enterprises, universities, and research institutes, in the hope of doing the local economy good and finally making the local citizens' lives better.

Yulin is a resource-rich city. If its natural resources had been found prior to the Reform and Opening-up, probably Yulin's municipal government would not have been influential enough as most of the regulation functions have been performed by the organisation in charge of managing local natural resources. Daqing is a case in point. Cities of this sort have relatively weak government compared with their resource regulation bodies, as, first of all, natural resources are usually found in remote areas. As a result, before the natural resources were found, government bodies were not well developed. Therefore, the central government would establish a managing body, a special organisation in charge of the development of the extraction of the resources as well as the development of this place. This sort of organisation has various names across different regions and their names change as time goes by. Some were called managing committees, some were called bureaux. In the 21st century most of these organisations have become companies, but the

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[38] One reason is that China is the largest producer of coal and semi-coke.

[39] The information in this section originated in 'A study of the strategy of sustainable development of Yulin's semi-coke industry', a government report issued by the Yulin Municipal Development and Reform Commission.

managers or directors still have quasi-governmental authority and often move into government posts. All the ensuing development of this place will proceed according to the needs of resource extraction. Under such circumstances, it is extremely difficult, if not impossible, for the local government to interfere with the operation and development of the local mining industry. To some extent, it is safe to say that the mining regulation body predated the local government. If we use the analogy of the relationship between the Prussian state and the army, the relationship between the mining regulation organisation and the local government does not consist in the local city owning a coal mine or oilfield. On the contrary, the mine or oilfield owns a city. When the Triple Helix approach is used to study these mining cities, one thing the researcher should bear in mind is that the Triple Helix in operation in these cities is quite different from those in other Chinese cities, let alone those in western cities. The government helix and the industry helix in this Triple Helix overlap with each other or even merge.

Then another question arises. The Triple Helix approach has been developed in western contexts, so is it suitable in Chinese contexts? After all, the Triple Helix becomes a double helix in the context depicted above. (This will be discussed further and in greater detail later.) As for the System of Innovation and the Innovation Ecosystem, the local government can do little to improve them. If the mining industry or oil mining industry in a specific area is of importance to the country, the administrative level of the mining regulation body will be high, sometimes as high as the mayoral level or even higher. For example, in Mentougou District,a suburb of Beijing, the leader is at the bureau level which is as high as the mayor of a local city, while the manager of the local mining bureau is also at bureau level. In Shijingshan District, another district of Beijing, where steel giant Shougang Group is located, the manager of Shougang is a vice-minister, which is higher than the leader of Shijingshan District. In these two cases, the local government cannot order or force the mining company or steel company to do anything; they have to negotiate with those companies. The case is similar in Daqing. In these cities, the Triple Helix does not exist, or exists in a quite different way. The System of Innovation is relatively closed and displays parochial features, while the innovation ecosystem is not very dynamic. Consequently, these cities have experienced a process of transition, having suffered economic recession in the past. This can be partly explained by their innovation model, the less vibrant innovation atmosphere, while the autarkic style of knowledge-production gives rise to the scarcity of innovation and the slow pace of innovation diffusion. Apart from that, cities or regions of this category tend to have a longer mining history than other mining cities. When the decision-makers (the manager of the company alone or in co-operation with policy-makers) decided to launch a radical transition, the natural resources are going to be depleted, and lack of natural resources is tantamount to a lack of financial resources. All this results in only a few successful transition stories.

Yulin belongs to another category. Its mining industry took off around the 1990s, at a time when the municipal government had been firmly established and could shoulder all kinds of responsibility. As a result, the resulting development of coal mining and related industry in Yulin was under the scrutiny of the municipal government. Different branches of the government were each in charge of a specific part of the mining development. The Development and Reform Commission, the Bureau of Science and Technology, the Bureau of Industry and Information technology, the Bureau of Finance [40]all played their unique role. Of course, in China the party system is more authoritative than the government. The Party Committee of Yulin also exerts its influence on the local mining industry. In the mining cities more often than not, the government helix is the core of the Triple Helix as it is usually stronger than the other two helices. The local firms tend to be small, thereby possessing less bargaining power compared with large SOEs. As for research institutes, the newly emerging mining cities are always located in relatively remote

[40] Those government bodies’ names changed and sometimes new bodies were established, while sometimes old bodies were eliminated. In this thesis, the current government bodies are the main research targets.

areas, thus they seldom have enough human or financial resources to provide for research institutes, so they either have rather small academic organisations or, worse still, do not have a research institute. Under these circumstances, the government's choice is pivotal in shaping the outlook of the Triple Helix of Yulin. The System of Innovation and Innovation Ecosystem in Yulin is also heavily influenced by government actions. The government in Yulin tried to diminish the distance between local industry and universities and research institutes, namely, create opportunities for knowledge users and knowledge producers to communicate smoothly. As a remote city, Yulin does not have sufficient knowledge production sites thus inviting outside partners is necessary. Most local companies are small and are not far-sighted enough to make strategic decisions. The municipal government makes every endeavour to bridge this gap. Its effort can be generalised so as to make the System of Innovation more open to outsiders (non-local participants), provide the functions which are essential for an Innovation Ecosystem, and building platforms for the three helices to share experiences and exchange ideas. Not every mining city's government does the same, neither have all of them achieved great success, as we will see at the end of this chapter. Luckily, at least as far as the Triple Helix framework is concerned, Yulin's local semi-coke industry has had periodic success, although it became slower due to tough years in the coal mining industry.

5.1.2.1 The early period

During the development of the semi-coke industry in Yulin, the municipal government played different roles. In fact, it did not directly take part in this industry during its burgeoning years, namely, in the 1980s. Around the late 1980s, some local coal mining companies attempted to cope with the recession of the coal market and the difficulty of transporting coal to other provinces by trying to invent a new method to produce coke from coal. The method was not arrived at by careful scientific research or accurate laboratory experimentation but by trial and error, and the inventors were not well-trained researchers. This is a typical learning-by-doing style of innovation and it was inspired by practical concerns. In order to obtain coke or semi-coke, people should put the coals together and pile them up, then burn them. After the coal has burnt completely, water is used to extinguish the fire and the semi-coke can be obtained. This method is easy and cheap, and the semi-coke can be used as a reducing agent. This has assisted local coal mines to sell more coal, and develop new business partners. It was so popular that in Yulin even people who did not have coal mining experience began to be active semi-coke producers. This method was the product of a certain period of time, representing the earliest exploration of the semi-coke industry. The weaknesses of this method, however, are also apparent. The technique is too simple and not advanced enough, the quality of the product is unstable, and the success rate is not high. As the main product, only the semi-coke can be put onto the market. The by-product, namely, the coal tar and coal gas, cannot yield any commercial value. Furthermore, this method does not utilise state-of-the-art equipment so it produces lots of pollutants.

The 1990s witnessed the rapid development of Yulin's semi-coke industry. More advanced equipment was used, and the backward semi-coke producing method introduced in the previous paragraph was eliminated. A new form of tool called a vertical furnace [41](Zhili Lu or 直立炉.) began to replace the older method.

The semi-coke obtained by using the older method is called ‘man-made semi-coke’, while that obtained by using the vertical furnace is called ‘machine-made semi-coke’. According to the relevant data, by 2006 there were 294 semi-coke factories, annual production quantity stood at 20.04 million tons, and over 12,000 people worked in this industry. However, because the production of each factory was still small, the technology used was not frontier technology, and the geographical distribution of the factories was sparse, the semi-coke industry during this era was still considered

[41] According to an official working for Yulin Municipal DRC, these furnaces were mainly local products. Some were produced by semi-coke companies themselves, some were bought from other companies. As the semi-coke industry is largely a Chinese industry, few international companies design products for it.

to consume too much energy and pollution resulted, thereby the method was in danger of being eliminated.

Figure 7: A photo of a vertical furnace

That period was unique. Economic development or, in other words, the pursuit of GDP, is the most important, even the sole target, of government. As long as it can enhance the local economy, the method's dark side was ignored, or at least downplayed, by the authorities concerned. Consequently, whilst this method caused severe pollution,[42] wasted natural resources, and was low in efficiency, there was no government interference to curb this trend or to minimise its side effects. In general, the semi-coke industry during this period was in a laissez-faire situation, the government's role being to try every means to increase the production output of the industry so as to accelerate local economic growth. The government acted as an invisible hand, retreating from the regulation area, and allowed 100 semi-coke factories to flourish. Although it did not do too much to assist these factories' development, to some extent the government removed all the barriers and relieved

[42] After adopting new methods, the pollution has been reduced but as it is a business secret for semi-coke companies, the relevant data cannot be obtained.

the factories' burden. Meanwhile, government officials accumulated precious knowledge of semi-coke, which became critical in the upcoming years.

5.1.2.2 Post-2007

Government regulation and industrial policy appeared from 2007. In that year, the government issued two important policies. The first is 'The suggestions on structural adjustment and the development plan of Yulin's semi-coke industry', the second is about the technology level of semi-coke factories, and it increased the technological entry barrier of this industry. Then the municipal government closed all the 271 small semi-coke factories whose production capacity was below 600,000 tons a year, built 17 semi-coke industry parks, and five semi-coke production sites. More advanced machines were introduced and spread throughout the city. For example, the SJ-III vertical furnace produced by a local company, and the SH2007 vertical furnace designed by Shaanxi Metallurgy Research Institute. The scale of semi-coke activity was sharply increased and, with the help of the new equipment, not only the semi-coke but also the other two by-products, namely, coal tar and coal gas, were collected and processed. In 2008 the Ministry of Industry and Information Technology approved the industry access criterion of the semi-coke industry, meaning that the semi-coke industry was no longer deemed a local industry but would be regarded as a national industry. After that, several other state ministries such as the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration of the PRC, issued regulations for the semi-coke industry. The approval Yulin gained at the state level attracted attention from various spheres. Several state-owned enterprises began to invest in Yulin's semi-coke industry, new factories were built, new technology was put into use. All this made the semi-coke industry the pillar industry of Yulin. Other locations in China also recognised the significance of developing the semi-coke industry and started to catch up. The success story of Yulin inspired their imagination and the experience of Yulin laid the foundation for the future development of this industry. Other semi-coke production bases include Xinjiang, Inner Mongolia and Ningxia. In

2012 China produced 48,100,000 tons of semi-coke, among which Yulin alone produced 40%, while Xinjiang produced nearly 30% of total production. In summary, as a pioneer of the semi-coke industry, without Yulin's effort, the value of semi-coke and its derivative products would not have been accepted at such a speed, and there would not have been such a large sum of money poured into this industry. As for the future development of the semi-coke industry, Yulin will probably once more be a leader.

5.1.3 The status quo of the semi-coke industry in Yulin[43]

After nearly three decades' development, the semi-coke industry has become the largest coal chemical industry in Yulin. It has linked its upstream coal mining industry, its downstream chemical industry, and its electricity generation industry together and spurred the development of transport and commercial services.

In 2012, the year I was an intern in Yulin, the semi-coke industry and its downstream calcium carbide, and magnesium (Mg) industries were combined, the total workforce was 46,805 employees, and the company realised 27.37 billion yuan (US$4.34 billion) output value, 12.9% of the entire output value of the counties which had semi-coke industry. Meanwhile, the tax paid by semi-coke companies was 1.24 billion yuan (US$197 million), around 12.6% of the revenue of the counties which had semi-coke industry. By 2016, there are 83 semi-coke companies in Yulin. The production capacity is 49.5 million tons, actual production in 2014 was 26.2 million tons, while the corresponding figure for 2015 was 25 million tons. As for the other two by-products, in 2015 Yulin produced two million tons of coal tar and 13.6 billion cubic metres of carbonised coal gas. Consumers of these products include enterprises in Inner Mongolia, Ningxia province, and some other provinces of China. Two thirds of the semi-coke are used to produce calcium carbide and ferrous alloy.

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[43] The information in this section comes from a series of government reports compiled by Yulin Municipal Development and Reform Commission.

Yulin first proposed the idea that, before using coal, the coal tar must be obtained. Under the guidance of this idea, Yulin has established a complete industry system which aims at utilising coal with a high efficiency and in a clean way. This has something to do with China's natural resource endowments. China has a rich coal deposit but lacks oil and natural gas, so if oil can be obtained by processing coal, the profit can be greatly augmented. By now, Yulin's Making Oil from Coal programme has a production capacity of 3.42 million tons a year. Because of the shrinking market (the coal and crude oil markets), however, in 2015 the actual production capacity was only about 588, 600 tons.

The semi-coke industry in Yulin has a complete industry chain. Around the 1990s, the semi-coke industry in Yulin could only utilise the solid product, which was the semi-coke. Regarding the other two forms of products, the local factory had nothing to do with them and let them go. With the advancement of machines and updated thinking, coal tar and coal gas have been attached more importance. The following industry chains have been highly developed, that is, coal-semi coke-calcium carbide, coal-semi coke-ferrous alloy, coal-semi coke-coal tar-fuel oil, and coal-semi coke-carbonised coal gas-magnesium. Some new discoveries led to the extension of this chain. For example, the cost of producing magnesium can be reduced by 25% or so by using the coal gas obtained during the semi-coke producing process. As a result, the Mg production factories swiftly moved from Shanxi, a neighbouring province of Shaanxi. Now Yulin has become the largest Mg production base in China, perhaps even the world. The Mg it produces occupies 41% of Chinese and 36% of world output. In fact, although this industry is still called semi-coke industry, the semi-coke itself is no longer the sole product, sometimes it is not even the most valuable product. As this industry is still called the semi-coke industry, this research will follow the same trend. However, I would stress that the semi-coke industry points to the whole industry chain rather than one part of this chain.

Apart from this, Yulin is exploring a more environmentally friendly way of producing semi-coke. By now, all the semi-coke companies have adopted a set of equipment to protect the environment, such as installing protective net, isolating the coke and coal storage warehouses, coal gas collection equipment etc. In the past, water was widely used to cool the red coke down. One of the products of this process is ammonia water (because there is plenty of nitrogen in the air), and it used to be directly discharged into rivers. Now new technology has been adopted to deal with the ammonia water, numerous new clean technologies will be tested and utilised.

This striking development by no means guarantees the healthy update of the semi-coke industry, nor does it mean that the challenges facing the semi-coke industry in Yulin have been solved. In fact, whilst Yulin’s achievements in recent years constitute a big improvement, some newly emerging challenges are quite troublesome, entailing more investment and novel ideas. If the grand background of the Chinese macro economy and the mining industry are taken into account, to some extent the current situation is becoming tougher. After all, Yulin's semi-coke industry, Chinese mining as a whole, and the whole country has entered a transition period, and nobody knows what it will look like in the future.

The biggest challenges Yulin needs to tackle include updating its equipment and technology and looking for new markets for semi-coke and its derivatives. The key term here is ‘innovation’, both technological innovation and innovation of its business model.

More specifically, first of all, Yulin's semi-coke industry faces the problem of excess production capacity. This problem can be attributed to a historical legacy. Prior to 2007, governments seldom engaged in the development of the semi-coke industry, thus many local citizens opened their mini semi-coke factories which are difficult for the government to regulate, while controlling their production capacity is a problem. After 2007, the municipal government took action to encourage mergers and acquisitions in this industry in the hope of acquiring the power to control the production capacity of semi-coke. This strategy is effective. The problem is that, during this industry integration process, the coal mining industry suffered a sharp downturn and the semi-coke industry was negatively influenced, thus some semi-coke factories began to suffer heavy losses while the integration process was still in process. Whilst the number of semi-coke companies has been reduced from nearly 300 to around 80, the total production capacity is still far above national demand. The overcapacity problem is still severe. Second, Yulin faces a dilemma, that is as a city boasts for its coal production, the local semi-coke industry lacks the coal it needs to process in order to obtain semi-coke. This is because most of the coal Yulin produces is powder coal (粉煤), rather than lump coal(块煤). The former type’s particle diameter is quite small, usually below 20 mm, while the latter’s is above 30mm. The SJ-III vertical furnace is the most popular stove used in Yulin. It almost accounts for 80% of the whole Yulin market, but it can only process lump coal. If purchase lump coal, the cost of producing semi-coke would be increased by at least 20%. According to a survey, Yulin can sell about 40 million tons of lump coal, which only produce 23.5 million tons of semi-coke, which is only 50% of the semi-coke production capacity. Moreover, whilst the technological level of Yulin's semi-coke industry has been improved, this kind of improvement is not great enough. The new environmental regulation has imposed ever higher requirements on the mining industry. By 2012, no local semi-coke industry was able to meet these requirements. As for the industry access standard set by the Ministry of Industry and Information Technology, only two enterprises in Inner Mongolia have passed it. In summary, Yulin's semi-coke industry faces its second shutdown.

In conclusion, Yulin's semi-coke industry is at a crossroad. Making the best use of its natural resources and realising the promotion of industrial structure is vital for Yulin's future. However, crises sometimes reveal hidden opportunities. The following section discusses Yulin’s adoption of systemic approaches.

5.1.4 The government's role in bolstering the development of the semi-coke industry

The municipal government of Yulin plays a major role in the development of the semi-coke industry. This section will introduce the role the government plays. The information in this section comes from reports issued either by one government branch or co-issued by a number of government branches. I obtained these reports from Yulin's Municipal Development and Reform Commission, as this municipal DRC orchestrates all the development of the local semi-coke industry. Some documentation consists of speeches at a government conference, some reports to superior officials. All the data are in Chinese.

It is widely known that in China when the term 'government' is used, its meaning is different from its use in the West because it also incorporates the Chinese Communist Party (CCP)'s organisations. By and large, the CCP's organisations are mainly in charge of work linked to superstructures, say, the propaganda and the grand strategy setting. The government bodies are mainly in charge of local regulation and economic development. As a resource-rich city, Yulin's government bodies are relatively strong, while its party organisations seldom directly engage in local economic affairs, although the party secretary is still the paramount leader of the city. As it mainly focuses upon innovation, a socio-economic phenomenon, when the term 'government' is used in this research it refers to the administration bodies only rather than party organisations. The most important policy-making organ in Yulin is the standing committee of the Communist Party, and the development strategy of semi-coke industry has to be approved by this standing committee. Apart from that, the party organisation in Yulin seldom directly engages in the development of the industry, although most of the decision-makers in government are Party members themselves.

The remaining part of this section will shed some light on what the municipal government of Yulin does to assist its local semi-coke companies or semi-coke industry to grow. These two are different. As some non-Yulin companies have built their plants or laboratories in Yulin, the municipal government supports them as well.

The term ‘government’ has been used countless times, but what exactly it means in Yulin's context will be elaborated here. Above all, there is no one single entity called ‘government’. In China, there are various kinds of administrative branches that constitute a complete government. In these case studies, the relevant government bodies include the Municipal Development and Reform Commission (MDRC), the Bureau of Industry and Information Technology (BIIT), The Bureau of Finance (BOF), The Bureau of Science and Technology (BOST), The Municipal Government Office (MGO) and so on. These government branches each perform their function in the development of the semi-coke industry, and their co-ordination has produced a series of government documentations. They either issue policy together or they issue different policies in the same area respectively. These outcomes reflect the fact that each government branch still has its own turf as, for the fields in which multiple branches need to co-operate with each other, they need to issue policies jointly. Consequently, each government branch's role will be illustrated respectively in this part of the chapter. Only when the branch being discussed plays a leading role will this procedure be attributed to this branch's action. In fact, most of these projects were undertaken by the BOST and the BIIT. When it comes to the MDRC and BOF, they almost participate in every single project. The National Development and Reform Commission is often dubbed a mini state council. Similarly, the DRC at the municipal level is like a mini municipal government. It often acts as the initiator of the co-ordinator of a project, as does the MGO. As for the BOF, as long as the project requires government financial support, without the approval of the BOF, this project will not get the required funding. Based on the foregoing, some concrete projects organised by the BOST and the BIIT will be introduced first, and then the financial support of the BOF will be described. Finally, the MDRC’s and MGO's roles will be introduced. In some cases, the government's main task is to build bridges between local companies and universities or research institutes, and the research projects undertaken by these academic organisations will also be introduced. Another reason why it is more proper to introduce the work of these academic organisation is the technical or scientific nature of their work. This is not an engineering or natural science thesis, so it will not go very deep into technological details. Therefore, it is not useful to allocate one independent section to the role of those academic organisations. Their role is to provide technical services to the local semi-coke companies which lack in-house R&D facilities. Besides, as the local semi-coke companies in Yulin are relatively weak in technological capabilities, it is difficult for them to find a strong technological partner. In most cases, Yulin's government establishes communication channels for the local companies. Naturally, many government actions are tightly linked with academic organisations.

5.1.4.1 The Bureau of Science and Technology (BOST)

When discussing issues related to technological innovation at the municipal level, the BOST cannot be bypassed. It is the most professional government body in charge of formulating scientific policy. All the parties involved have arrived at a consensus about the significance of innovation in the development of the semi-coke industry. The BOST's main responsibility is to follow each scientific co-operation project and evaluate its performance. Sometimes BOST officials need to provide guidance to local businessmen or look for appropriate partners for universities or research institutes. The BOST in Yulin has done a lot of work to make Yulin's semi-coke industry more prosperous. This includes the following:

First, identifying the key technologies which are essential for the future development of the semi-coke industry. BOST has identified four groups of key technologies: the updating of the current vertical furnace; the powder coal's carbonisation technology; the extension of the coal tar processing industry chain, and improving the efficiency of utilizing coal gas. Each group of technologies can be further divided into different technologies. Horizontally, they cover a wide range of technological areas. Vertically, they start from the selection of semi-coke raw materials and end with the processing of the final products of the semi-coke industry. One can draw a detailed technology route map by reading through this list. Most local semi-coke factory owners are not well educated. They are just local residents. Some became rich through coal mining in the past decade. They do not hold a university degree in STEM (Science,Technology,Engineering and Math) subjects, but with such a list to hand, they feel safer and more confident. By comparing the technology their factories possess with the promising technologies identified by the BOST, they can decide where to invest their money and bear in mind their own strengths and weaknesses. This list is like a benchmark for all the local companies. It aims at channelling scarce resources in the right direction. Other government bodies also make reference to this list when local semi-coke companies apply for financial funding to support their technology updating programmes. When someone wishes to build a new semi-coke production plant, getting the approval will be decided by whether the technologies they are going to adopt meet the requirements of this list.

This strategy has seen good results. By now, Yulin's semi-coke industry has applied for 214 patents (in 2015 alone, 52 patents were applied for), among which the invention patents category[44] numbered 57, 26% of the whole number applied for. A total of 162 patents have been granted (in 2015 alone, 41 patents were granted), among which the invention patents numbered 49, accounting for 30% of the whole number applied for.[45]Valid patents number 117, among which a quarter are invention patents. Compared with other industries, the semi-coke industry has become the model in terms of the drafting of patents.

Second, by communicating with semi-coke companies, BOST hesitate to adopt new technologies. One of the reasons for this is that they are heavily taxed, thus any

[44] In China, there are three categories of patents. They are the invention, utility model and industrial design. The invention patent is considered as having the highest technological element.

[45] Some patents are held by companies. In some cases, companies and co-operative research institutes are co-holders of the patent, while a few patents are held by individuals.

increase in investment represents a risk for these companies. According to Yulin municipal government's calculation, when all the taxes and regulation fees are put together, a semi-coke company should pay 67.5 yuan for each ton of semi-coke, while by selling one ton of semi-coke the company only receives 390 yuan. BOST report this issue to the municipal government, hoping that by taking the pressure off semi-coke companies, the technology can be diffused at a higher speed.

Third, BOST plays an active role in the planning of new semi-coke industrial parks. During the early development period of the semi-coke industry, as there was almost no government planning, the semi-coke factories were scattered in different places such as Yulin. As long as a mine owner had enough money and wanted to transfer to the semi-coke industry, he could just do it and would not encounter strong resistance. To some extent, this situation was similar to what economists describe as the 'perfect market'. The outcome of this dispersed decision-making process is the small scale of each production unit and the geographical dispersion of semi-coke factories. The dire consequences of which include underinvestment in R&D and environmental pollution. For example, if a stove is too small it becomes uneconomic to install environment protection equipment. BOST participated in the planning of 22 semi-coke industrial parks, while the roads and other infrastructure were all built by the government. Semi-coke companies were encouraged to move into these parks. It facilitates the formation of industry cluster and industry intensification. The upstream and downstream of the semi-coke industry also moved into the parks, reducing the whole industry chain's costs.

These industrial parks have relatively strict entry requirements. They must have an annual production capacity of over 600,000 tons, and must have an automation control system. These policies point to the drawbacks of the old-fashioned and small semi-coke companies. They sometimes count on experienced technicians to control the temperature of the stove and the carbonisation time length, which leads to the unstable quality of their products. The construction of the industrial park aims at eliminating backward production units and creating advantageous conditions for factories using state-of-the-art technology. The companies in the parks are also required to abide by modern company law. The management effectiveness and the safety and profit levels all have been lifted. Some large SOEs such as Shaanxi Coal and Chemical group and Yanchang Petroleum group have expressed interest in investing in the development of the semi-coke industry.

Finally, the BOST has also helped local companies establish long-term co-operation with academic institutes. Over 20 university research institutes and large SOEs have become technology partners of Yulin's semi-coke companies. The BOST also proposed to establish a semi-coke engineering technology and research centre in Yulin. This centre has developed a whole set of semi-coke clean production and resource utilisation equipment, possessing the intellectual property of this equipment. At the moment, this centre, together with other semi-coke companies and academic organisations, are doing R&D in various kinds of critical technologies. More than 20 projects have been approved by the national, provincial, and municipal governments.

5.1.4.2 The Bureau of Industry and Information Technology (BIIT)

At the national level, the Ministry of Industry and Information Technology (MIIT) was established in 2008 as an outcome of the so-called large department reform(大部制改革). Its main body and personnel was made up of the former Ministry of Information Industry. Its functions and authorities lie in regulating various industries, setting industry access standards, supervising the daily operation of the industry, pushing forward the development of critical equipment and indigenous innovation, and protecting national information security etc.

A BIIT is the MIIT at the municipal level. The functions are almost the same, so as the pillar industry of Yulin, after 2008 when the MIIT was established, the semi-coke industry never lacked the involvement of BIIT. It is one of the most important government bodies for the semi-coke industry.

Similar to what the BOST has done, the BIIT also help local semi-coke companies find strategic allies. The difference is that the BOST is more technology- driven while the BIIT is more project-driven. The aim of BOST is to help local semi-coke companies enhance their technological capabilities or accelerate the adoption of a new equipment. All the activities BOST participate in must have something to do with technological advancement or scientific discovery. The mere expansion of a business or the increase of production quantity is not the prime concern of BOST. While BIIT, focuses more upon the industry's output, pure Science & Technology issues are not its prime concern.

One of the most influential business partners BIIT found for Yulin's semi-coke industry is Shenhua Group, one of the largest coal mining companies in the world. The BIIT contacted Hebei provincial Development and Reform Commission, and got the three parties to sign a strategic contract. This contract aims to utilise Shenhua's transport capacity to sell cleaner semi-coke to Hebei. One of the disadvantages of Yulin's semi-coke industry is the lack of transport. The infrastructure is not developed enough in Yulin and some semi-coke factories are far from the urban area[46], In order to transport semi-coke to its end users, expensive transport costs will be incurred by semi-coke producers. By developing an alliance with Shenhua, this problem can be largely mitigated. Shenhua has its own trains and its transport network covers a large area. This makes it a perfect partner. As for Hebei's provincial DRC attendance, this is because Hebei needs clean fuel to support its steel industry and reduce pollution. One partner is a provincial government, the other is a giant SOE. Without the work of the BIIT, tiny local semi-coke companies cannot get in touch with the other two parties. This agreement can definitely make the three parties better off, whereas it

46 Because by now the semi-coke producing process still produces a large amount of pollutant substances

might not have happened without the active role played by the BIIT.

Second, one task which can only be performed by the BIIT is to lobby national authorities to establish semi-coke industry access standards. This work is one of the functions of the MIIT. It will only establish national industry access standards for industries considered to be strategic and significant to the country. At the very beginning, only Yulin produced a statistically significant amount of semi-coke, so this industry was regarded as parochial, and at that time the special physical characteristics of semi-coke had not been widely recognised. Thanks to the efforts of the BIIT in Yulin, officials in the MIIT began to pay attention to semi-coke. Of course, Yulin's BIIT did not do this alone, but it was the leading agency. Setting a national industry access standard has several merits. First, it means that this industry is no longer local and is deemed to be linked with national interests. Moreover, as Yulin is the most active driving force behind this process, some of its own interests will be reflected in the standard. Finally, the bringing together of national authorities enjoin many gifted people and thereby compensate Yulin’s brain drain. After all, it is only a third or even fourth-tier city. With this access standard to hand, the national authority is like the backup force of local government. It can be used as a weapon to encourage technological investment or the shutdown of unqualified plants. To sum up, this access standard has gained for Yulin's semi-coke industry a ticket at the central theatre and it has become a business card for Yulin.

Meanwhile, the BIIT is an endeavour to help local semi-coke companies search for new uses for of semi-coke. Understanding of semi-coke is become deeper and more comprehensive. This can be attributed to, first, more scientific discoveries which have exposed the features of semi-coke more thoroughly, and second, as the semi-coke industry has left Yulin, those who work in this industry are keen to look for a more promising downstream industry in the hope of digging for more potential consumers. Two examples will be given here.

The first is the co-operative experiment between Shaanxi Provincial Department of Industry and Information Technology and Xi'an Thermal Power Research Institute. They conduct research to understand semi-coke's physical characteristics and chemical characteristics better. The ultimate goal is to test whether semi-coke can be used in power plant stoves. Through this research, the advantages of semi-coke as power plant fuel have been identified. Semi-coke has is more environment friendly, it contains less pollutant elements, and it has higher thermal value. At the same time, its disadvantages have also been identified. It may be harmful for the stove and it can lead to slag bonding. The conclusion of the research is that, in order to make the best use of semi-coke, a power plant can combine it with other kinds of fuel and the researchers give concrete suggestions to the power plants in Hebei about how to use semi-coke. The aim of embarking upon such research is to rely upon a third party to prove the benefits a power plant can obtain by using semi-coke. No single semi-coke company in Yulin is able to finish this task, as they have scarcely had the chance to develop personal networks with the scholars. The contribution of the BIIT (contacting its superior agency DIIT at the provincial level) cannot be ignored.

The second example is the experiment to test the effect of using semi-coke in steel production. Shaanxi Steel group and the University of Science and Technology Beijing participate in this project and have each done their own experiments. In Shaanxi Steel's experiment, semi-coke was found to have the economic advantage. It increases the proportion of fuel but as it is cheaper than anthracitic coal (when burnt, anthracitic coal does not give off smoke), the total cost of fuel is reduced. The University of Science and Technology Beijing[47] arrived at a similar conclusion. It points out that, as the cost of fuel in iron-making takes up 90% of the whole cost, semi-coke can help steel and iron makers reduce their costs. Although semi-coke's technical quality is worse than the fuel it replaces, the reduction in cost can compensate for the drop in technical quality. These two organisations are also invited

47 It used to be a university specialised in steel-making.

by the BIIT.

In summary, the BIIT's participation in the semi-coke industry is largely based on the projects it selects. These are carefully chosen for the sake of Yulin's semi-coke industry. It has given rise to the increasing demand for semi-coke. If we compare this with the behaviour of the BOST and the BIIT, the following conclusion can be drawn. The BOST assumes that the demand for semi-coke is a given. The best way to make Yulin more competitive is to improve the quality of its semi-coke products, while the BIIT take the technological level of semi-coke as a given, and try to enlarge its demand pool. In this light, the two agencies are indispensable.

5.1.4.3 The Bureau of Finance（BOF）

The Bureau of Finance is in charge of drafting an annual budget and allocating the revenue of the municipal government. No government plan can be implemented successfully without the support of the BOF. The BOF seldom directly engages in a specific semi-coke project, whereas it possesses the decision-making power associated with providing government funding.

The role of the BOF in the development of the semi-coke industry is more indirect than the MDRC, the BIIT and the BOST. It does not push a single project itself, but in most cases, it co-operates with other government agencies and when discussing the total amount of money the government needs to invest it usually has the final say. Viewed from this angle, its influence is by no means less than other government agencies. Government investment is an obvious sign of political will It is never simply a figure as it tells the market and other parties, say, a university, what the government wants to achieve and to what extent.

In order to support the local semi-coke industry, the BOF has approved the establishment of a special fund established in 2014 and called: 'the special fund for the update and transition of the semi-coke industry'. Each year the BOF allocates 50 million yuan (about US$8.14 million) to this fund. Meanwhile, the Bureau of Finance at the county level is required to invest the same amount of money in supporting the semi-coke industry. This fund is granted to the following projects:

A. Market expansion. This mainly refers to the expansion of semi-coke products, new brand-building, and the management of local semi-coke products.

B. Industrial update. This refers to the technological transformation project and current companies' industry access, the diffusion of advanced and mature technology, and the update of critical equipment.

C. Science and technological innovation. This refers to the R&D of critical and general-purpose technology in semi-coke and other relevant industries, the introduction of large coal pyrolysis equipment, the establishment of Science &Technology centre etc.

D. Basic research. This refers to basic theoretical research by the semi-coke industry, research into industrial policy, the compilation of development plans, standard setting, and technology consultation.

E. Environment Protection. This refers to the construction of environment protection equipment and R&D in environment protection technology and its diffusion.

As for the fund’s selection process, the municipal government has established a committee of experts. Some of the most influential figures have been invited to join this committee, each year the municipal government sends the applications to each expert and asks for their feedback, and their choices determine who can get this fund and the amount they get. This process is seen to be fair to all the applicants. The selection criteria is whether applications meet the direction of technological advancement, while the judges possess expertise in particular areas, guaranteeing that the limited funds go to the right place. In fact, even after this fund has been granted, it is still under strict supervision. In 2014 the committee decided that 19 projects would be supported and the total amount of fund was 19.4 million yuan (about US$3.16 million). But only 17 projects obtained the fund and the actual fund granted was 14.22 million yuan (about US$2.32 million). The BOF advised allocating the remaining fund to the next financial year and the performance of these projects was evaluated before granting the fund.

Besides, in order to encourage the sale of semi-coke products, the BOF would award semi-coke companies which achieved an increase in revenue and taxation. Companies which realised a 30% increase in revenue and taxation would receive 300,000 yuan (about US$48,900), those which realised a 20% increase in revenue and taxation would receive 200,000 yuan (about US$32,600), and those which realised a 50% increase in revenue and taxation would receive 500,000 yuan (about US$81 400).

The BOF uses this financial support as leverage to adjust the development pace of the semi-coke industry. This policy has achieved partial success, some companies using the money to purchase new equipment, invest in technology updates, while these actions in turn increase government revenue.

5.1.4.4 The Municipal Development and Reform Commission (MDRC)

The Development and Reform Commission has always been dubbed a mini-government, for it is regarded as a mini State Council. Everything in relation to economic development falls in its domain. Although the functions of the DRC at different levels are not the same (the trend is that the lower the level the less functions a DRC has), it often serves as a pilot agency in economic development. The functions of the DRC cover almost every aspect of daily life. It makes economic plans, regulates industry access and exit, adjusts prices of some special goods, authorises the construction of railway and highway infrastructure, and is also in charge of proposing reform plans and supervising the macro economy. In short, where there is an economy, there is the DRC. Without the co-operation of the DRC, other governments can hardly achieve anything. In this section, the role of the MDRC in the development of the semi-coke industry will be introduced.

As mentioned, I undertook an internship in the Yulin MDRC in 2012, and it was in around 2012 that the coal mining industry began to suffer an abrupt downturn. When I worked for the MDRC, terms such as ‘transition’ and ‘innovation’ kept being used by different people. Of course, ‘semi-coke’ was also a catchword at that time. Anxious officials of the DRC went to different factories in the hope of getting first-hand information about this industry. During an interview with the Chief Engineer of Yulin's MDRC, he apprised me of the work done by the MDRC to bolster the semi-coke industry. Most of the big projects were proposed after 2012. The role of the MDRC during this arduous process is like that of the BOF. They are each singly responsible for each project. The BOF realise this goal through control of the allocation of government funds, this way for DRC has the authority to decide which project can get approval.

One of the biggest advantages of the DRC is information. First of all, compared with other government branches, the DRC is much more comprehensive and concrete. This can be seen even in the names of each government branch. Most other branches are professional, say, the Ministry of Science and Technology, Ministry of Agriculture - they specialise in their own turf. The DRC, however, has turfs which overlap with most other government bodies. This puts the DRC at the centre of an information network. No other agency is as equipped as the DRC to glean information about what is going on in other parts of China or even the world, or what is happening in other industries. There is a famous proverb in a Chinese poem. The reason why you cannot see the real appearance of the mountain is that you are on this mountain yourself. If the semi-coke industry is a mountain, the DRC can observe it from the top of other mountains, and it can go to many mountain tops, thus the policies it designs should be more accurate in grasping the overall trend.

Second, compared with local semi-coke companies, DRC officials tend to be better educated and think strategically. Many newly established semi-coke factories were constructed in industrial parks, but most old production plants are still scattered around the whole city. Even companies in the park are not prepared to open them up to their competitors. One of the direst consequences is that the semi-coke companies do not know what other companies are doing. Sometimes one company was found to be doing what had been proved to be wrong by other companies. Under such circumstances, DRC officials help semi-coke producers exchange information. DRC officials get useful information by going to factories, universities, and research institutes themselves. The local companies do not have perfect information collecting systems. They probably specialise in one part of the semi-coke industry chain. The managers of those companies might not have the chance to visit other companies. Being fully aware of this situation, the DRC established an information exchange centre providing useful and almost free information to local semi-coke companies.

Recently, the MDRC of Yulin has found 'a new continent' for semi-coke. As is widely known, Beijing and its neighbouring province Hebei are notorious for being heavily polluted. Much research has been done to find the cause of the soaring PM2.5 and numerous methods have been tried to reduce the pollution. Yulin MDRC found that semi-coke can make a contribution to Beijing’s, Hebei’s, and Tianjin's environment. The fact is that there are many sources of air pollution. The pollutant gases given off by the stoves in steel plants used to be regarded as one of the main sources, as a result, the national government imposed strict requirements on all the steel plants. After several years’ effort, it is reported that a further reduction would be very difficult, if not impossible. Another source of pollution is the civilian warming stove. It has not received the attention of government thus it has major reduction potential. The production process makes semi-coke a perfect burning material for household use. A large proportion of the pollutant substances contained in coal have been removed through carbonization. If households can use semi-coke rather than coal to keep warm, the air would be fresher. The DRC organised a group of scholars and contacted the Chinese Academy of Science to conduct relevant research. They published a report in which the technological and economic feasibility of replacing coal with semi-coke for household warming were studied. The result is quite positive for semi-coke. The provincial government of Hebei and Yulin municipal government has signed semi-coke using contract. The government would subsidise households who agree to use semi-coke to replace coal, as semi-coke is more expensive. If millions of households use semi-coke, the downstream market could be expanded and air pollution in Hebei could be improved. One interviewee said in2016 that the price of coal almost doubled, which caused semi-coke's price to increase as well. Consequently, many households gave up the use of semi-coke. This partly explains the heavy pollution which appeared at the end of 2016.

The MDRC showed up in almost any critical moments of semi-coke industry. It launched petition to the Mayor of Yulin and the Municipal Party Secretary and successfully persuaded the leaders of Yulin to paying special attention to the semi-coke industry. Some new ways of supporting the semi-coke industry occurred to the DRC officials and the strategic significance of the industry for Yulin was first recognised by DRC officials. Arguably, the blueprint of Yulin's semi-coke industry was drawn up by the MDRC of Yulin.

The roles of various government branches in the development of the semi-coke industry in Yulin have been fully elaborated. Some other agencies' roles, such as that of the Bureau of Environmental Protection and the Government Office, are quite similar to one of the agencies introduced above. Whether the government should directly engage in economic development is always controversial among scholars. It is safe to say that the government's role in this case is worth appreciating. They do not enshrine the magic power of the perfect market and do not shirk their responsibility. The game between Yulin's government and the semi-coke companies is definitely positive sum.

5.1.5 Some case studies of the semi-coke industry

In this section, some specific cases will be presented. In the last section, what the municipal government did was reviewed. The co-ordination work and strategy of governments are of significance in the development of the semi-coke industry. It is a reflection of political forces. Ideas, however, cannot change the world. The semi-coke companies' reaction is worth looking at, as without the change in the behaviour of the local semi-coke companies, government efforts will be in vain. Yulin's semi-coke community is a diverse family. There are mini -semi-coke production units, there are also semi-coke companies backed by large SOEs. Their reactions and their relationships with governments and universities will be studied here.

5.1.5.1 Jingfu （京府）Coal Chemical Company

This company was established in 1998 and it is a typical semi-coke company. It is considered typical because it is an average company, neither too small nor too big, and the business it operates is also a classic semi-coke business.

Jingfu purchases coal from mines, and processes the coal by using its own equipment. It first washes the coals, then put the washed and selected coal into vertical furnaces. The coal in the stove will be carbonised, and decomposes into semi-coke, coal tar, and coal gas. The coal gas will be used to generate electricity. The company itself can use electricity generated by this method, and if there is still surplus electric power, the company will sell it to someone else. Besides, Jingfu Coal Chemical Company also uses coal gas to produce Mg and sell it.

The other two products semi-coke and coal tar, are the main products for almost all semi-coke companies. Jingfu is unable to further process coal tar so it directly sells it to a company which has the equipment to process coal tar. As for semi-coke, Jingfu’s most important product, it can either directly sell it or use semi-coke to produce calcium carbide. The business model described above has been adopted by almost all the semi-coke companies in Yulin. It is the classic model. Big companies or small, their business models are somewhat similar. What distinguishes an advanced company from others is the processing technology. When the MDRC officials in Yulin advised me to visit Jingfu Coal Chemical Company, the reason they gave is that this company has government funding to update its coke quenching method.

Jingfu used to use the coke wet quenching (CWQ) method, not in order to meet the stricter requirement on environment protection but because it has invested in adopting the method:

> Coke Dry Quenching (CDQ) is an alternative to the traditional wet quenching of the coke. Coke is cooled using an inert gas in a dry cooling plant, instead of cooling by sprayed water which results in high CO2 emissions and thermal energy loss. This process allows the recovery of the thermal energy in the quenching gas which can then be used for the production of steam and electricity, for district heating, and/or for the preheating of coking coal. CDQ also improves the quality of coke and enables reduced coke consumption in the blast furnace. As the product quality is improved, CDQ may also allow for the use of lower cost non-coking coal in the process, thereby reducing costs.[48]

The CDQ process is essential to semi-coke production. Yulin's government has decided to encourage the semi-coke companies in Yulin to adopt the CDQ method. Jingfu reacted to the government's appeal, as a result both the municipal and county governments have offered a generous subsidy to Jingfu. This update does not destroy the older production plant, it only entails the installing of new equipment on the current stove. Using the funding from the government and Jingfu's own investment, except for one stove, all other stoves have been updated.

In this case, innovation only appears in the last step, which is the selling of the new product. The CDQ technology being used at other places was adopted to improve the local situation. It is a kind of innovation diffusion, not creation. As the company itself

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[48] http://ietd.iipnetwork.org/content/coke-dry-quenching viewed on 2016-12-10.

is unable to promote technology, it is practical to help it update its technology. From this perspective, the company and government facilitate the diffusion of innovation. This function is no less important than the creation of innovation.

5.1.5.2 Jinfengyuan（锦丰源） Clean Coal Company

The second company is an experimental production plant. It was established in 2008 and only has 25 employees. The unique feature of this company is that it is a private concern, but The Institute of Engineering Thermophysics (IET), which originated from the Power Laboratory of the Chinese Academy of Science (CAS), is one of its stock-holders. The aim of opening such a company is to test the technology of powder coal pyrolysis. Due to the change in the coal mining method, it is reported that a large proportion of the coal (about 70%) produced by Yulin is powder coal. The vertical furnace is used in the semi-coke companies in Yulin. However, it can only pyrolyse lump coals. This has caused a dilemma. The semi-coke company has to choose between purchasing more expensive lump coals or pour lots of money into the R&D of powder coal pyrolysis technology which might cost more money. Jingfengyuan represents one attempt to solve this problem.

Jinfengyuan is the fruit of co-operation between companies and research institutes. The scientists in CAS live and work in Yulin in summer. They perform industrial experiments in powder coal pyrolysis technology as theoretical work is one thing, the industrialisation of the technology is quite another. They take three steps to finish the whole process. First is the selection and drying of coal, then the pyrolysis of the selected powder coal, and finally the coal tar collection and purification process.

This experiment has achieved partial success. It can turn more coal into coal tar. While common equipment can only turn 7% of the coal to coal tar, the corresponding figure for JInfengyuan is 10%. This is an internationally recognised indicator. Besides, the coal gas collected as a by-product has higher thermal value, and can be used to produce natural gas. Finally, Jingfenyuan reduces the production cost of semi-coke by expanding its raw material from lump coal to powder coal. At this stage, its industrial experiment in full load has been tested. The next step is to sell this technology to other companies or to establish its own production plant.

During this seven-year-long process, the municipal government offer three million yuan (nearly US$0.5 million) to support the experiment, while the government of Shenmu County also provides three million yuan. Jinfengyuan itself found six million yuan in funding. The reason for doing so is that the powder coal pyrolysis technology has been identified as essential for all the semi-coke companies in Yulin. Once developed, all the participants of the semi-coke industry can benefit. This kind of non-appropriated technology needs government support. The government's logic is to accelerate the development of such technology and from the beginning, the government has taken part in this process. When the experiment finishes, as a stakeholder, the government can encourage the company to disseminate relevant technology. In the end, the whole semi-coke industry in Yulin get the profits. It can be concluded that Jinfengyuan' was set up to test the technology, as it is a large industrial laboratory. When I visited Jinfengyuan, as it was cold and all the scientists from CAS had returned to Beijing, the site had in fact stopped production. Only maintenance work still proceeded. Jinfengyuan is a special way to cope with technical problems, and the role each party plays is also worth studying.

5.1.5.3 Shenmu Fuyou（神木富油） Energy Company

This company used to be privately owned. It was established in 2006. In 2008 Shaanxi Coal and Chemical Industry Group became the largest shareholder, so now it is a state holding company. Compared with the companies introduced in the previous two sections, this one is much larger. Its mother company, Shaanxi Coal and Chemical Industry Group, ranked 416th in the world's 500 largest companies. This is quite different from the other companies examined above. During an interview, one of the managers stated in early 2016 that the company tested its own powder coal process equipment after some successful experiments in the laboratory and all the theoretical problems have been solved. Unfortunately, during the test the equipment had some technical bugs. As a result, this experiment failed. The company is organising another test. This test is one critical step in the company's blueprint. The failure of the test postponed the company's plan to build a complete industry chain. At the moment, it still buys lump coal from a coal mining company. The main business of the company is the latter half of the semi-coke industry chain, namely, the processing of the semi-coke, coal gas, and coal tar.

Shenmu Fuyou boasts of its “coal, low to medium temperature carbonisation and independent ownership technology of coal tar oil hydrogenation”, and the construction of 1.2 million tons of low temperature carbonisation is being accelerated. This full-range LCT (low temperature coal tar) fixed bed HDT (hydrotreatment) process produces naphtha, diesel oil, and FCC (Fluid Catalytic Cracking) raw material (Zhu et al, 2015, pp434). Shenmu Fuyou's Technology for catalytic hydrogenation of full range middle/low temperature coal tar to produce intermediate distillates" (FTH) was awarded the second prize of the National Science and Technology Progress Award for energy. According to the scholars at the Chinese Academy of Engineering, this technology is the most advanced in the world. It first purifies the coal tar obtained from the carbonisation of coal, then hydrogenates the purified coal tar. It can increase the recycle rate of the coal tar and improve its quality. Shenmu Fuyou chose to prioritise technology from its inception, its managers often discuss technical questions with R&D staff, such unique features distinguish Shenmu Fuyou from other small semi-coke companies.

5.1.6 Conclusion of the Yulin case

Yulin's semi-coke industry has experienced its ups and downs in history, but from the grassroots semi-coke processing method to craftsmanship, the lessons we can draw from this case are valuable.

From the perspective of the System of Innovation, semi-coke companies themselves should be regarded as major contributors to innovation, and innovation entails the co-ordination, or even co-evolution, of all the components and the relationships between these components. In Yulin's case, during its burgeoning period, the semi-coke companies themselves accomplished the task of innovation because the relevant System of Innovation per se was also growing, and many critical institutional settings were lacking at the time. In the following period, the semi-coke industry formed an industrial cluster in Yulin, whereas the elements of a System of Innovation were still scarce. This could be attributed to the lack of environmental protection policy, relatively small companies, and the seemingly infinite supply of raw materials. In time, when the significance of semi-coke had been recognised by other provinces of China, the first-mover advantage Yulin enjoyed finally disappeared. One way to regain a superior market position is to create performance gap, then the formation of a System of Innovation begins to seem important. It first became to grow into a real System of Innovation. Some components of this system, such as universities, research institutes, governments and SOEs, began to participate in the innovation of semi-coke-related technologies. Their interactions made this System of Innovation more complicated. Besides, this System of Innovation has gone far beyond the regional dimension. Any resources in this country that can be utilised to yield semi-coke-related innovation would not be ignored. The two trends happened concomitantly, and they mutual strengthen each other. When discussing innovation in the semi-coke industry, the days when only local semi-coke factories can be mentioned are long gone. Smooth knowledge flow channels have been established in this system, and its core is the semi-coke company. They actively search for the solutions they encounter in their production lines, and the government is happy to help local firms get in touch with academic organisations which might make a difference. This kind of benign interaction has become the new norm.

The Triple Helix framework can provide another interpretation. Except for the industry helix, the other two helices were lacking in the early period of the semi-coke industry. This sole helix could neither provide stability like a double helix situation nor provide room for the creation of innovation. It is very fragile, any slight change in the outside world might influence its direction of growth. Then government participation not only adds one helix to this interaction, it also lays the foundations for participation by universities and research institutes. As previous sections depict, most semi-coke factory owners do not care too much about the prospect of this industry or Yulin city. They were only interested in taking advantage of Yulin's resource endowments, their goals are the same, namely, to grow rich. Government officials tried to redirect the passion of those factory owners to benefit the owners and the city. Then the semi-coke industry has the government as its driver to guide it., At the same time, the imagination and efforts of the industry, as well as its academic staff, will determine the speed. The diversity of the interaction between the Triple Helix is interesting. The three cases chosen in this chapter belong to different categories. The first case, Jingfu, is an established company which sought technical assistance from the university and government helix. The second case, Jingfenyuan, is only a testbed for a specific technology. It is actually an industrial laboratory and a production unit simultaneously. The third case, Shenmu Fuyou, has the strongest technological capability among the three, alone playing the role of industry and university. Comparing the status quo of the three companies, Shenmu Fuyou is far more promising than the other two. It has more talented personnel, more grand blueprints, and a more reasonable institutional setting. Using the Triple Helix lens to observe the three cases, we may conclude that, for a modern enterprise, the internalisation of the university helix into the industry helix seems to be more promising.

The Innovation Ecosystem approach illuminates the idea that a System of Innovation should be viewed dynamically and that the increased diversity of an innovation ecosystem will make it more robust. Yulin's case vividly justifies these arguments. The Innovation Ecosystem of Yulin's semi-coke industry is becoming more complex. As more elements are integrated into this system, it can perform more functions and the ever-increasing interactions leave space and create opportunities for innovation. Successful intervention by Yulin's government is due to the fact that most of these interventions aim to make this ecosystem more dynamic rather than putting everything under the control of government. The small and local ecosystem is trying to make the best use of exogenous factors to provide novel functions. The more open, more dynamic ecosystem makes the semi-coke industry's development healthier.

In summary, the semi-coke industry in Yulin can be analysed by systemic approaches, and these approaches complement each other. As a fast-moving innovation event, Yulin's semi-coke will keep growing.

5.2 The Building of the System of Technological Innovation at Haohua Energy Company

Haohua Energy Company is a listed company. A constituent company of JIngmei[49] Group, it operates all the large and state-owned coal mines in Beijing. Currently, Jingmei Group owns 62.3% of Haohua's stock share, and the joint second largest stock-holders of Haohua are Shougang group and China National Coal Group, holding 1.86% respectively. Recently, Haohua's practice of building a System of Technological Innovation has been awarded second prize in the Science and Technology competition organised by the China National Coal Association. Most other rewards were given for a specific technological breakthrough, while efforts in the improvement of innovation management are rare. As technological innovation is becoming increasingly important among mining companies, most firms have established technology centres. As a result, it is worthwhile studying a classic case of this sort. This case study will contribute to a more comprehensive understanding of how a modern Chinese coal company views the significance of innovation and how it endeavours to make the best use of technology from both inside and outside the company.

[49] 'Jing' is short for Beijing, 'Mei' means coal

Compared with Yulin's semi-coke case, Haohua demonstrates another facet of the System of Innovation in Chinese mining industry. Firstly, this is a case study of a company, while Yulin's case is a study of a local industry. A study of a company can display more detail than an industry study. A study of a local industry is a meso-level study, while a study of a company might be attributed to micro-level study. A meso-level study is more suitable to demonstrate interactions between innovation subjects and the environment but might be weak in describing in detail what the real innovation process is within a company. By contrast, a micro-level study is more suitable to depict a clear innovation chain, from the motivation for innovation to the completion of an innovation, while it might be unable to demonstrate how the change of environment exerts its influence on those innovating companies and the evolution of a whole innovation ecosystem.

Second, in the Yulin case, the role of government in regulating and stimulating the semi-coke industry is paid special attention, while company reactions are not paid much attention. As this is a study of a company, in the Haohua case government policy will not be attached much importance and the company itself will be the main actor. In Yulin's case, the municipal government serves as a multi-function organisation. Apart from performing the function of government, it also behaves like a consulting company, sometimes generating earlier and more accurate analysis regarding the vision of a technology or a niche market than local semi-coke companies. In Haohua's case, the role of the company will be examined rather than government regulation.

Third, Haohua is a much more complicated company than the majority of semi-coke companies in Yulin. Some semi-coke companies are merely production units or, in other words, semi-coke factories. Haohua, by contrast, is a modern corporation. It was established strictly in accordance with relevant laws and, moreover, it is a listed company. It is obvious that its governance structure is more rationalised than the privately owned semi-coke companies in Yulin. Haohua is also much larger. Although in terms of the production quantity, Haohua cannot match a coal mining giant such as Shenhua, and the total production of coal in Beijing cannot match that in Yulin, the situation is quite different if we compare Haohua with any single semi-coke company. Haohua almost incorporates all parts of a coal mining industry chain, from prospecting to marketing, while it also gets assistance from its mother company, Jingmei Group, which runs a variety of businesses whether relevant to coal mining or not. Jingmei is a large coal mining conglomerate, and can provide sufficient resources to its constituent companies. The administrative level[50] of Jingmei Group is almost as lofty as the district where it headquarters are located, which is bureau level, or, in other words, as high as Yulin City. To some extent, Haohua company itself can realise the Triple Helix interaction with its own boundary.

Fourth, what Haohua is doing is typical coal mining while the Yulin semi-coke case is more of a study of metallurgy. In a narrow sense, mining is about resource excavation, digging. This is just the core business of Haohua. It runs a number of coal mines, and its innovations in mining methods enjoy a certain reputation in China. Yulin's semi-coke is the downstream of coal mining. It is about activity that adds value rather than coal mining per se. The companies in Yulin's case are not coal mining companies. They buy coal from coal mines and utilise special methods or equipment to process it. In Yulin's case, the companies are coal consumers, while Haohua is a producer of coal. They belong to different parts of the industry chain. As a result, Haohua demonstrates many features that are different from semi-coke companies in Yulin. Its interaction model with governments and universities is also different.

Finally, Haohua is owned by an SOE located in Beijing and this SOE is managed by the State-owned Assets Supervision and Administration Commission of the People's

[50] The administrative level of a company is not stipulated by law, but it is an unspoken rule that an SOE does have an administrative level. In the future, de-administration reform will finally cut the link between SOEs and governments, but at the moment they are not incommensurable.

Government of Beijing Municipality. While most semi-coke companies in Yulin are privately owned, whilst Shenmu Fuyou is a subsidiary of an SOE, it used to be a privately-owned company which had been purchased by a large SOE. The locations are also worth mentioning. Yulin is a city in a remote area. There are plenty of resources for Haohua to utilise, but there are also many more strict rules for Haohua to abide by.

5.2.1 Basic information about Beijing's coal mining industry

It is said that Beijing is the only capital city which still has a coal mining industry. (Things will change in three years, as all the remaining coal mines have been ordered to close by 2019). Thanks to the tradition of documenting the history of almost every ancient Chinese dynasty, it is easy to keep track of the history of Beijing's coal mining activity. According to the records, the earliest coal mining activity in Beijing can be traced back to the middle of the 10th century. At that time, Beijing became the southern capital of the Liao dynasty. Being the capital of a large empire entails much higher energy consumption. In order to support the royal family's various activities, the coals in Beijing began to be excavated. After the Liao dynasty, coal mining in Beijing continued. Interestingly, after the Liao dynasty, except for several decades' interval, Beijing continued to serve as the capital city for nearly a thousand years. Scholars provide many reasons to explain why all the following dynasties chose Beijing as their capital, the rich coal resources are definitely being one important reason. Coal enabled the imperial governments and the rank and file to keep warm and relieve the heavy burden incurred by the vast population. During the Ming and Qing dynasties, as Beijing became the capital of the empire, the demand for coal grew sharply, and the number of people who engaged in coal mining also increased. During the Ming dynasty, a great many coal workers paraded into the capital city and the whole imperial government was shocked[51]. During the Qing dynasty, foreign forces began to control Beijing's coal mining industry. In the 1860s, the British

[51] This might be the earliest workers' parade ever recorded in Chinese history.

ambassador negotiated with the Chinese government over whether foreign companies should be allowed to mine coal in Beijing. Afterwards, some coal mines owned by local capitalists invited British technicians to join them and use foreign technologies. Around the decline of the Qing dynasty, lots of foreign countries found Chinese partners and established joint ventures. They brought in advanced technologies and mining methods, thereby improving the technological level of Beijing's coal mines. Infrastructure also assumed a central role. Railways and roads were built. All these construction works gave rise to the expansion of the coal market and improvements in productivity. Before the founding of the People's Republic of China, Beijing had approximately 400 coal pits and 13,000 workers (The History of Beijing's Industry: The Coal Mining Industry, 2000, p.5).

After the founding of the PRC, the scattered coal mines to the west of Beijing were nationalised, and the People's Government of Beijing established a regulation agency to ensure that coal production was under the control of the government. During the ensuing decades, new and more modernised coal mines were designed by Chinese engineers and constructed by Chinese workers, and, like other industries, they could not avoid being influenced by the political atmosphere. After the end of the Cultural Revolution, the development of the coal mining industry in Beijing took a fresh course. Investment in science and technology was increased, and some state-of-the-art technology was adopted. Furthermore, the main regulation body, the coal mining bureau had transformed its business strategy from coal mining only to a multi-product and multi-industry strategy. In 1990, Beijing Municipal Coal Mining Bureau realised an industry output value of 224 million yuan. It employed 59,326 workers, including 6000 technicians. It owned eight coal mines and produced 6.02 million tons of coal. It ranked 333rd among all Chinese companies in terms of sales' value (Ibid, p.8-9). To sum up, coal mining in Beijing has a time-honoured history. By 1990, it had made a great contribution to the development of Beijing and its more affluent citizens.

The 1990s need to be mentioned independently, since they are considered to be the toughest years in coal mining history after the founding of the PRC. Coal miners used to be civil servants, but after Deng Xiaoping proposed a socialist market economy, coal miners did not have the so-called 'iron rice bowl' any longer. Besides, in the 1990s the price of coal was extremely low, some mines were shut down, and a great many workers were laid off. Coal mines tried every means to increase sales and reduce costs. At the end of this tough decade, an organisational innovation occurred, which was the establishment of Jingmei Group. The municipal coal mining bureau, which produced the coal, and the coal company (in charge of selling the coal) merged and the new company was named Jingmei Group. This group has many businesses and the business strategy of the coal mining bureau changed. Jingmei Group's various businesses reflect this transformation.

Regarding Haohua Energy Company, most of the coal mines were under the control of Haohua. It is in charge of guiding the development of the coal mines. In other words, Haohua has inherited the legacy of the older coal mining bureau. It runs four coal mines, three in Beijing, one in Inner Mongolia. In 2010, it produced five million tons of coal. In 2015, dubbed the most miserable year for coal mining, Haohua produced about 10 million tons of coal, of which the west Beijing area produced 4.5 million tons, while the mine in Inner Mongolia produced six million tons. It realised revenue of over six billion yuan and a profit of 40 million yuan. In the first half of 2016, the situation became even worse but, fortunately, in the latter half of 2016 the price of coal soared and the life of the coal mines has become much better. According to government regulation, all the three mines in Beijing owned by Haohua will stop producing coal, marking the end of Beijing's coal producing history. This long history is approaching its end so this case study will be written as some sort of a memorial. This history began with a pure manual power input and ended with a technological model for other coal mines, this dramatic change lending this 1,000-year story a happy ending, although its legacy and experience will be felt far beyond the boundary of Beijing municipality.

5.2.2 Haohua Energy Company's efforts to establish a System of Technological Innovation

5.2.2.1 An introduction to the technological innovation agency in Haohua

Nowadays, most mining companies in China have established various kinds of innovation management agencies, Haohua is no exception. The agency in Haohua is called Technology Centre, and it is in charge of the company's technological innovation affairs. The director of the Centre is the Manager of the company. In China, this kind of arrangement is always used as a political signal. It conveys the message that the company attaches due importance to technological innovation. In fact, the Manager is just a figurehead of the Centre. Seldom interfering in the daily operation of the Centre, he is regarded as a representative of the high-ranking managers of the company. The real leader of this Centre is the Vice-Director and the General Engineer. Meanwhile, this Centre also has four branches in the four mines mentioned above (three in Beijing, one in Inner Mongolia). All the directors of the four subsidiary technology centres are the administrative chiefs of the mine (the real chief of a state-owned mine in China is the party secretary), while all the vice directors are the general engineers of those mines. This arrangement is a top-down setting in order to ensure the management of technological innovation gets due attention in every production unit. After all, as a coal mining company, the Technology Centre at headquarters cannot make any improvements if its link with the coal mines were cut off. Most of the innovations originated from practical needs, the problems encountered in each mine are the largest source of those needs. This top-down arrangement establishes a smooth information exchange channel, thereby facilitating interactions between the production line workers and the technicians or engineers. Moreover, it leaves space for grassroots innovative ideas to be heard by senior management staff, thus making bottom-up knowledge dissemination possible. The Centre also has six professional research institutes. Each institute is in charge of a specific area. For examples, the Research Institute for Information Technology and its Applications, and the Research Institute for Safety Technology and Engineering. The directors of these institutes are also the vice managers of the company. These organisations are in charge of the daily innovation management. At a higher level, Haohua company also has an institution responsible for grand strategy and making decisions regarding the direction of the next technological advancement. It is called the Technology Commission. It is not only the supreme decision-making agency regarding technology at Haohua but also for the whole JIngmei Group. This commission has two director members; they are the Chairman of the Board and the Manager of Haohua. It also has eight vice-director members, all of which are high-ranking managers at Haohua, and 17 other members which include the leaders of the relevant offices and some professors of Shandong University of Science and Technology. According to the company rule, this commission ought to have at least two meetings a year. In case of emergency, it can convene a meeting at any day.

This organisational arrangement is designed to make technological capability one of the core competences of the company. All the paramount leaders of the companies hold positions in one innovation management organisation or another. This reflects the attitudes of the company towards technological innovation. The company tries to bring in outside intellectual resources to bolster its relatively weak technological capability. It has established long-term co-operation with some academic organisations, including Shandong University of Science and Technology. The inside and outside resources have been stimulated to create innovation and augment company profits.

5.2.2.2 The practice of technological innovation at Haohua

Having established a series of institutions and organisations to provide support for innovation activities within the company, what Haohua does to fulfil the tasks of this arrangement is also essential for successful innovation.

Above all, the company offers financial support for all innovation activities. The grant for supporting technological innovation will be allocated to each project according to relevant rules. During the 11th Five Year Plan (from 2006 to 2010), Haohua invested 429 million yuan (US$63.1 million) to conduct R&D activities. In 2010 alone, Haohua invested 156 million yuan (US$22.9 million) for R&D, accounting for 3.3% of its revenue. During the 12th Five Year Plan (from 2011 to2015), Haohua invested 834 million yuan (US$128.3 million) to conduct R&D. To be more specific, in 2011 Haohua invested 162 million yuan (US$25.7 million) which took up 3.5% of the company's revenue. In 2012 its R&D investment was 185 million yuan (US$29.4 million), or 4.3% of total revenue. In 2013 200 million yuan (US$32.2 million) was invested in R&D, occupying 4.3% of Haohua's revenue. In 2014 Haohua invested 122 million yuan (US$20 million) in R&D. Whilst this represented a sharp drop, it still accounted for 4.6% of the company's revenue. This year's increase in the proportion of R&D investment was realised with great difficulty. It can be argued from the 2014 figures that, in that year, Haohua's revenue decreased to a large extent. The overcapacity problem had been widely recognised by 2014. The price of coal began to plummet, which had a huge negative influence on Haohua's business. Regardless of all the barriers it needed to overcome, Haohua did not choose to sacrifice its investment in R&D. In 2015 the situation became even worse, whereas Haohua had invested more than 4.6% of its revenue in R&D.

The investment to R&D can be further divided into different usages. These include: direct investment, incorporating investment in materials, fuels, and energy; personnel welfare, incorporating insurance and housing allowances; depreciation charges for R&D; operation fees and rental charges for R&D; testing fees and machine purchasing fees and fees for evaluating and accrediting R&D outcomes. Besides, Haohua invests even more money in co-operating with universities and research institutes when its own technicians or equipment cannot accomplish a certain task. These expenditures have special regulation rules and the Technology Centre has the authority to either deny or agree the relevant grant. Haohua's own

R&D resources can be relied upon to solve some production-related problems, its ability shifting to the development part and incremental innovation. As a result, it is necessary to look for academic partners outside the company. These researchers also need to find business organisations to conduct research if they hope to apply for state funding. Mutual demand ties the mining companies and universities together. Haohua is a case in point. Its investment in its innovation partners not only solve problems but also help scholars. This kind of friendship is by no means established randomly. Each mining company faces unique problems determined by the geological structures of the mines it runs. At the same time, different universities or research institutes also have their own strengths and weaknesses, so they will try to find the appropriate partners. In an interview with a member of the technical staff at Jizhong Energy Group, I was told that Jizhong has an in-house research institute, but it focuses upon a narrow range of research fields, thus might be unable to offer sufficient technical support for the company. It would be more economic to find other organisations which already possess the expertise to tackle the problem facing Jizhong at any given moment than to invest in its own research institutes. Actually, this is the current situation facing Chinese mining industry. There are a huge number of small technological agencies each specialising in a clear-cut domain. As for the large and comprehensive organisations, there are not enough.

Haohua actively choose academic projects to support. The staff at the Technology Centre collect information from coal mines, and the engineers and miners working in the coal pits report to the Technology Centre the most urgent problems they need to tackle. Sometimes the R&D personnel go to the coal mine themselves to obtain first-hand information about the technology being used. They will detect if there is any potential opportunity for technological innovation or if there is any threat to the safety of the miners or to the sustainable production of the mine. They will make predictions and take precautionary measures to prevent some problems from appearing. A competition mechanism is also introduced. Haohua employs outside technicians and academic staff, evaluates the contributions of these personnel, and if an employed expert receives criticisms during the evaluation, their contract with Haohua might be terminated. Apart from punishments, Haohua also design reward institutions. One institution worth introducing is a special innovation grant tailored to ordinary workers. The aim is to encourage all workers to participate in innovation. Whoever makes a contribution to the company through innovation, will receive a reward. This conveys the message that the company believes that everyone can be an innovator, that innovation will not be monopolized by engineers or university researchers. From 2013-2014, a total of 865 projects received the grant, totalling 1,633,650 yuan. It is not a large sum, but as the main beneficiary of these grants are average miners earning several thousand yuan per month, it can still make a difference. Except for the innovators, the advisors of these project also receive a special reward. They might get 1,000 yuan if the project is at the company level, whereas they can get 3,000 yuan if the project is at the national level. Based on the foregoing, we may conclude that financial rewards are used as a tool to promote innovation at various levels and by people from different backgrounds.

Haohua launched six movements to make sure that technological innovation can be understood and appreciated by the whole company. First, the company convenes a monthly meeting to discuss technological innovation. This meeting has been merged with the meeting for all the general engineers. All the participants are general engineers (or vice-general engineers) of the company or the coal mines owned by the company. At the meeting, all the technical problems will be presented and discussed. What should be done the next month will also be decided. This meeting is an information collection and exchange platform within the company. When a problem attracts enough attention—this may be due to its significance to the whole company or its extreme technical difficulty — it will no longer be regarded as a problem limited to one coal mine, but will be addressed by the whole company. By attending this meeting, the engineers and R&D staff can draw a clear technological route map for the company, while the overlapping investment will not be a severe problem.

Second, let us look at the masses' technological innovation movement. This movement is designed to inspire every potential innovator. The well-educated or scientifically-trained R&D staff are by no means the only source of innovation. They are key figures in solving big problems and complicated technical bugs, but when the miners encounter trivial issues it is neither economic nor efficient to turn to formal engineers for help. If the wisdom of the production line workers can be drawn upon, they always create technological miracles and bridge the gap between institutionalised research and practical studies. Therefore, Haohua organise special meetings for these grassroots innovators, their achievements will be demonstrated and evaluated, while formal institutions regarding how to award them have been established. This meeting is convened every three months.

Third, every six months Haohua convenes technological innovation project evaluation meetings. There are numerous technological innovation projects proceeding simultaneously. In order to make sure the company's investment is being used effectively and making real progress, the authorities concerned will launch mid-term evaluations. This meeting also serves as an experience exchange platform. The company might invite university professors to come, they assist the company's R&D staff. Meanwhile, the practical problems can also illuminate these researchers.

Fourth, every year Haohua will evaluate the outcomes of the technological innovation. This evaluation is a continuation of the mid-term evaluation. Some innovation projects will be rewarded.

Fifth, Haohua will assess the performance of R&D personnel annually. The R&D staff conduct the technological innovation, and as a result it is necessary to give each R&D person a fair assessment. Those whose performance was admirable over the past year will be rewarded, those who do not meet the basic requirements of the company will be warned or even punished. This assessment will be the foundation for the human resource management of the company. Innovation in its very nature always has a detrimental aspect. The creative destruction metaphor is still suitable to describe innovation. This feature entails a dynamic and vibrant environment. One way to realise this is through human resource management. By keeping the human resources flowing, the company can take in new knowledge and get rid of obsolete knowledge. Haohua's assessment activity rates the performance of the technical staff, and the most severe punishment is the revocation of contract. This institution facilitates the update of the company's knowledge pool and increases the flexibility of the company's recruitment policy. By now, Haohua has 3,668 people holding academic certificates at or above the junior college level (Da Zhuan, 大专),1,026 workers holding academic certificates at or above the college level, 75 people holding master's degrees, and five PhDs. Among all the technicians, 552 engineers have junior professional titles, 251 people have intermediate professional titles, and 81 technicians have senior professional titles. This talent pool publishes over 20 academic papers in journals at the national level or above.

Finally, Haohua has an annual technological innovation meeting. This meeting is both a summing-up of the past year's innovation activity and a planning meeting for the next year.

Haohua fully realises its limitations in R&D and the advantageous position of being a company in Beijing. The limited resources it has are not sufficient to ensure Haohua solve all the problems it encounters. But being based in Beijing, the hub of Chinese higher education and science and technology, Haohua can make the best use of extramural human resources. The Triple Helix functions well here. In Chinese contexts, policies aimed at enhancing interactions between the Triple Helix are called Industry-University-Research Institute integration policies. Haohua actively integrates itself into a network consisting of universities, other mining companies, and research institutes. Its geographical location is both a blessing and a curse. On the one hand, as we have seen, Beijing is the centre of Chinese higher education. It has the best universities and scholars. It teems with talents from other industries, while its expertise and R&D is unmatched by any other Chinese city. On the other hand, since Beijing is the capital city, the development of heavy industry is under the strict control of central government. Thus, Haohua is restrained by many more regulations than other mining companies. Besides, as Beijing is only a city, its land area is much smaller than large provinces, and this also restricts Haohua's development. Operating coal mines in other provinces is more difficult. Haohua's tactics are clear. Now that we cannot persuade the central government to changing its policy, what we can do is make the best use of the technological resources and realise potential innovation opportunities. Haohua gleans useful information by attending a huge number of academic conferences and seminars organised by other mining companies, government agencies, and public institutions. These activities assist Haohua's technical staff to identify promising technology, look for co-operation partners, and search for solutions to problems that cannot be solved by the company's own resources. Haohua R&D personnel can communicate with their colleagues from different parts of the country or even the world. Although Haohua’s R&D personnel themselves might not be the best and the research they conduct is far from the frontier of the field, going to these conferences can expand their outlook and help them keep track of the latest trends in the academic community. Yulin's semi-coke company managers do not enjoy this advantage. Acquiring valuable knowledge is just the first step. Haohua grasps the opportunity of establishing technology alliances with universities and research institutes, and these will be mutual beneficial to both sides. Sometimes Haohua also invite experts from home and abroad as its guest researchers. These professors will go to Haohua on a regular basis to give lectures and discuss problems with Haohua's technical personnel. Two successful cases are presented here. The first is the laboratory co-established with Shandong University of Science and Technology. It aims to prevent mine disasters and provide early warning systems. The second is the co-operation agreement with China University of Mining and Technology's Resource and Secure Mining laboratory, which is a national key laboratory. Haohua can utilise the laboratory results and ask the laboratory to help it train its technical staff.

We can conclude that, with organisational and institutional guarantees, Haohua has an Innovation Ecosystem of its own. It opens to the outside world and even invites the outside world to join its effort to make this ecosystem more sustainable and exuberant. It does not hesitate to welcome outside resources, and it has also built many information and knowledge transmission approaches within the ecosystem.

5.2.2.3 Haohua's achievements in technological innovation

The efforts of Haohua's R&D staff have yielded a rich harvest. In 2011 Haohua's Technology Centre was certified ' Beijing's Enterprise Technology Centre'. This is a certification granted by Beijing's municipal government. It aims to foster the core position of firms in innovation and technological investment. This certification is given to technology centres which have strong innovation ability, model-setting functions, and have achieved technological success.

	Enterprise Category	Revenue Million Yuan)	S&T activity investment (Million Yuan)	Number of R&D personnel	Original value of technology development equipment (Million Yuan)
1	Manufacturing	150	5	50	5
2	Telecommunications、Computer service and Software	120	5	80	3
3	Architecture	1500	7.5	50	10

Table9: Application criteria of Beijing's Enterprise Technology Centre (2011 version)

Source: http://www.1633.com/policy/html/beijing/shijingjixinxihuawei/2011/0808/30461.html.

Other requirements include the independent status of the Technology Centre and the establishment of a technology commission etc. In fact, Haohua's Technological

Innovation System is established according to these requirements. After receiving this certification, the company can apply for financial support from the municipal government when it seeks to construct a laboratory, or purchase R&D equipment or software. Each year the Technology Centre at the municipal level can get at the most one million yuan in funding, while the national level centre can get two million yuan. This is like a public announcement that Haohua will attach importance to technological innovation. The relevant regulations set norms for newcomers to follow and imitate. The change of institution will have an impact on the behaviour of members. Not being a typical high-tech company, Haohua's resolution and perseverance with pursuing a different path can be seen in this application and its actions afterwards.

In 2013 Haohua was certified as a high-tech enterprise by the Chinese government and became the second high-tech coal mining enterprise. In the same year, Haohua also received the certification of Zhongguancun High Technology Enterprise. Zhongguancun used to be a science park in Beijing, usually considered as the Chinese Silicon Valley. Now it has become a quasi-brand. Whatever is related to Zhongguancun is regarded as high-tech. These two certifications are both designed by the Chinese government. It sets high standards for enterprises, and as long as an enterprise receives the certification it can enjoy various kinds of privilege. Take the High Technology Enterprise certification for example. According to the latest standards set by the Ministry of Science and Technology, the Ministry of Finance, and the State Administration of Taxation, a high-tech enterprise needs to meet the following requirements: the enterprise should possess the intellectual property of its core products or services: the proportion of its employees who undertake R&D or innovation activities should be higher than 10%; for an enterprise whose revenue is over 200 million yuan, its investment in R&D should be higher than three percent of its revenue, while over 60% of the enterprise's revenue should be related to high-tech products or services, to name a few. After receiving the certification, a high-tech enterprise can enjoy a tax discount. Before receiving the certification, the enterprise's tax rate is 25%; this rate will be 10% less after it gets the certification. Meanwhile, the enterprise's investment in R&D can enjoy a tax discount as well. Different regions have their own policy for high- tech enterprises. Again, in 2013 Haohua was awarded the Advanced Enterprise of Coal Mining Industry in Science and Technological Innovation. This prize is the repayment for Haohua's endeavours in technological innovation. It is also one way the government can permeate its influence into targeted enterprises. This indirect tactic will be analysed later.

In 2015, Haohua enjoyed five important technological achievements. All received the second prize in the Science and Technology competition organised by the China National Coal Association, three other achievements received the third prize. Among the eight technological breakthroughs, three were appraised as reaching the international level (approximately over 90% of the top level). From 2014 to 2015, Haohua lodged 36 patents with the State Intellectual Property Office. Among the 36 patents, two were invention patents, the other 34 were utility model patents. The latter 34 have been granted. In 2015 two invention patents Haohua lodged three years ago were granted. By 2015, Haohua held four invention patents. The co-operation research project with China University of Mining and Technology about how to control falling rocks during the mining process was awarded the second prize of the Progress Prize in Scientific and Collective Technology by the Ministry of Education. An independent application to the Beijing Administration of Coal Mine Safety about safety supervision technology received the second prize of the Beijing Municipality safety production competition. Haohua undertook one part of 973 projects.[52]

[52] The 973 project provides comprehensive support to basic research. It was designed in the hope of cultivating great scientists. As it was acclaimed in March 1997, it is usually called the '973 project'.

Apart from these relatively marginal improvements in technology, Haohua has tried hard to change its whole coal digging and production system, and this has influenced the entire company. By and large, the geological structure of the coal mines in the western suburban area of Beijing is much more complicated than the average level in China. Its unstable coal and rock line make the digging and transporting dangerous tasks. The quality of the coal there partly compensates the risk of mining, as it produces anthracite, and west Beijing is one of most important anthracite producing areas. The anthracite produced here has been put onto the list of rare coals, which makes its price go up. Prior to the 21st century, coal mining is generally considered to be a high-risk industry. The risks, however, were to some extent downplayed or even ignored as, for a period, they saw rapid development, while the craze for energy can dwarf most other considerations. In the 2000s, governments issued a great many acts and regulations regarding the protection of workers in some high-risk industries, including coal mining. The precursor of Jingmei Group, Beijing Municipal Coal Mining Bureau, was perplexed by its high mortality rate. It is reported that, from the 1950s when the coal mining bureau was established to the late 1990s, 5.47 workers lost their lives for every million tons of coal produced. Even in 2004, when the mining bureau was replaced by Jingmei Group and Haohua, a severe disaster claimed 10 workers' lives. When Beijing was due to hold the 2008 Olympic Games, all the heavy industries within the local land area had to pass strict regulations if it wants to continue production. As a result, the pollution caused by coal mining is a key target of these environmental regulations.

Having decided to produce coal in a safer and greener way, Haohua organised a series of meetings to unify the ideas of cadres and workers, explaining the significance of updating its mining method and reducing the pollutant substances it gave off during the mining process. The first conclusion Haohua people arrived at was to adopt a mechanised mining method. The merits of this method are many. First, it is much more efficient than the traditional mining method, and the productivity of the company can be raised. Second, as it uses fewer workers in the mine, it is much more secure, decreasing the mortality rate. Third, the company can save money as it will employ fewer workers overall. The difficulty is the complicated structure of the mine and the affiliated resistance of the workers as well as some engineers. The managers of the company directly discussed with workers and engineers, persuading them to support this decision. Then Haohua invested 332 million yuan in the coming two years to transform and optimise the production system of each mine. This is not a micro change but systematic surgery. This effort finally paid off. In some years, no workers died, while productivity increased several times. Green mining was also a critical task Haohua had to accomplish. The waste rock was refilled into the mine, the waste water was recycled and purified, sometimes workers can use the recycled water to take showers, the dust was strictly controlled, and workers were encouraged to plant trees on the surface of the mining area. The twin strategy - mechanised mining and green mining - serve as two sources of technological innovation, representing a break with the past and imposing higher requirements for technology.

In the China Statistical Yearbook on the Coal Mining Industry (2013), the experience of Haohua was introduced. The lessons other coal mining companies can learn from Haohua are that, first of all, Hoahua dared to develop a set of comprehensive mechanised technology systems itself though the geological structure of its mines serve as a stumbling block; Second, Haohua was good at identifying the evolutionary trend of policy and thereby improving its utilisation effectiveness. For the first point, Haohua endeavoured to develop a new laneway setting model, a new mining method, new tunnelling equipment, and a new hydraulic support system. These innovations were all pathbreaking for west Beijing. When it comes to the second point, this might be a huge advantage for most companies in Beijing. They have a sharp sense of the political environment. As the hub of politics and S&T, companies in Beijing can take advantage of their location, getting the relevant information quicker, responding more swiftly to policy. Haohua's business strategy was in accordance with the requirements incurred by individual policies. Its effort to develop green mining technology is a case in point. After Beijing was chosen as the holding city for the 2008 Olympic Games, a series of policies were designed to make Beijing a more environmentally friendly city, Haohua chose the backfill of coal gangue[53] and the greening work of the mining area as two important tasks. The former not only reduces the environmental pollution of coal gangue but also reduces the construction cost of the foundation of the mine (Chen & Li, 2014). By choosing these fields, Haohua gained benefits from the improvement of technology and were able to get government funding. This is a clever strategy.

In conclusion, as a middle-sized coal mining company, Haohua have established a Technological Innovation System which incorporates inside and outside resources. The outcome of this system is useful for the company since it is based on its true concerns. This system helps Haohua to institutionalise its interactions with its technological partners, thus bind all the components of the system together. It creates an information exchange mechanism and encourages innovations of all sorts. It is also a component of China's National System of Innovation, the mining industry's Sectoral System of Innovation, as well as Beijing's Regional System of Innovation. Based on the fieldwork, my observation is that, at this micro level (meaning the research target is not a large SOE or multinational company), the impact of the National System of Innovation on an individual company is not direct. Just as the central government might not have links with all average citizens, the regional policy and sectoral regulation that construct the framework of each company. Compared with the smaller semi-coke companies in Yulin, Haohua has an obvious technological advantage. Consequently, Haohua plays a much more influential role in the System of

[53] In mining, gangue is the commercially worthless material that surrounds, or is closely mixed with, a wanted mineral in an ore deposit. Thus, it is distinct from overburden, which is the waste rock or materials overlying an ore or mineral body that are displaced during mining without being processed. See https://en.wikipedia.org/wiki/Gangue viewed on 2017-2-14.

Innovation, it is one of the major innovation contributors of the system, and has more positive interactions with other parts of the system. It proves again that a company's own technological capability, not the company's technological partners', determines what it can acquire.

The Triple Helix in Haohua's case is also different from that in Yulin's case. Haohua holds the dominant position in its interaction with governments and universities. Government plays the role of providing indirect guidance. It designs policies which either encourage companies to invest more in R&D or impose restrictions on technological indicators. Yulin's municipal government to some extent understands the semi-coke market better than the managers of those semi-coke companies, and officials in Yulin's government directly participate in the daily operation of semi-coke companies. While in Haohua's case, as it is located in Beijing, first, it is a company with a complete modern corporate governance structure, second, managers in Haohua have many more avenues to gain relevant information. Under such circumstances, officials in the Beijing municipal government seldom give explicit orders to companies. Haohua reads through government policies and chooses those beneficial to itself. For instance, the certification of high technology enterprise policy. Haohua decides to launch a transformation based on the model provided in this policy and enjoy the taxation benefits. Besides, Haohua also enjoys higher autonomy when it chooses its university or research institute partner. Although it cannot match the technical level of a university or a research institute level, it has access to a talent pool. This pool can help the company cope with daily technical problems. When engineers at Haohua face practical problems which entail a basic research ability, Haohua will reach out to find potential partners. Compared with the semi-coke factories in Yulin, Haohua's technological capability is far greater, and this endowment puts Haohua in an advantageous position vis-à-vis universities, and the company possesses more bargaining power when negotiating with its technological partners. Yulin's semi-coke companies do not have equal status with their technological partners. In fact, most of the semi-coke companies act as pure technology receivers, the universities and research institutes their supervisors rather than partners. The university scholars regard these companies as a larger industrial laboratory. During this co-operation process, the knowledge flows in one direction, from the university of research institute to the semi-coke companies. Or worse, the semi-coke companies do not get the technology, they just know how to use it. Much like the average consumer purchases electronic devices but has no idea about the technology. Haohua plays a much more active role alongside its co-operation with universities and research institutes. Of course, there are some large corporations in Yulin. Their role in the Triple Helix resembles that of Haohua. This proves that the stronger the technological capability a company has, the more it can acquire in its co-operation with other technology partners. This endogenous technological capability is decisive for a company to profit from the outside world, and it cannot be substituted by co-operation with any other organisation, such co-operation can at best be in the way of compensation. To sum up, in Haohua's case, the company is the leading player of the Triple Helix. The government and academic organisations do not dictate the interactions between the three players. the knowledge production of this Triple Helix is concentrated more on the company's needs.

Haohua’s Innovation Ecosystem is also worth discussing. It is not only a Sub-Ecosystem of Innovation in Beijing, but also a Sub-Ecosystem of Innovation in the Chinese mining industry. Generally, however, Haohua interacts with other coal mining counterparts, be it another coal company or a university or research institute specialising in coal mining. The relative simplicity of the ecosystem reduces the innovation potential and innovation sources. Meanwhile, Haohua almost monopolises the coal production of Beijing, this dominant position makes the motivation to innovate suffer. In the past decade, the political input, namely government policies, spurred the coal companies to rely more upon technology to fulfil diversified goals, such as to ensure miners' safety, increase productivity, and reduce the emission of pollutant gases. Governments at different levels and regulating different areas are considered to be component elements of a biocoenosis of this Innovation Ecosystem, that is, the evolutionary dynamics can be internalised. However, the single source of dynamics renders this ecosystem weak in vitality. A complicated innovation ecosystem tends to have more vitality. If most of the evolution originated from the same part of the system, this ecosystem always lacks future evolution dynamics. By now, the Innovation Ecosystem Haohua inhabits is still dynamic, but its prospects depend upon developing other engines to fuel innovation. Recently, due to heavy pollution, the government cut the production of coal on the one hand and turned to innovation on the other. The total closure of all the coal mines within the territory of Beijing will push Haohua to walk out. This might force Haohua to do more R&D, as it will definitely face an unfamiliar environment. A new mining method design and new equipment are needed. This means Haohua is going to be involved in a new innovation ecosystem (or a new Sub-Ecosystem of Innovation). New surroundings will give rise to more innovation opportunities. Haohua's technological innovation system will be useful in overcoming the difficulties which might occur in this new environment. We can summarise by saying that the sharp change, however passive it may seem, will bring more chances than risks to Haohua.

Haohua's case has demonstrated a number of divergences from Yulin's case, as different players perform different functions and various innovation strategies have been displayed. Yulin's semi-coke companies work in the metallurgy part of the industry chain. Haohua mainly focuses upon the mining part of the industry chain. The next case will be a study of a mining equipment manufacturer.

5.3 Tiandi Science and Technology Co, Ltd

In terms of annual revenue, Tiandi (天地) is the largest coal mining equipment manufacturing company in China . In 2015 its revenue was about US$1,785 million. My interviewees argued that China was still quite weak when it comes to mining equipment manufacturing. The aim of choosing one of the best equipment manufacturers in China is to first test if that statement is true and then explore the real technological capability of Chinese equipment manufacturers. This case study will introduce and analyse Tiandi's two technological breakthroughs.

5.3.1 Basic information about Tiandi

Tiandi Science and Technology Co. Ltd is owned by China Coal Technology and Engineering Group. It was established in March 2000 by the China Coal Research Institute and some other coal mining related companies. Its parent company was born of a merger between the China Coal Research Institute and Zhongmei International Engineering Research Institute in June 2008. The China Coal Research and Engineering Group is a central SOE directly regulated by the state-owned Assets Supervision and Administration Commission of the State Council (SASAC). Unlike other coal mining SOEs such as Shenhua, it is not directly involved in mining, but concentrates on equipment manufacturing and the relevant R&D. Its main business includes the production of mining automation equipment, mechanisation equipment, coal washing and processing equipment, technological services and consultation etc.

By the end of 2015, Tiandi had 23,762 employees, among which were 8,647 professional technicians, two academicians of the China Engineering Academy, 264 PhDs, 2,839 Masters, and 5,910 BAs. Since its establishment, the company has received over 600 science and technology advancement prizes, 1,904 patents (547 were invention patents). It had been certified as a high-tech enterprise from 2000. As a leading Chinese mining equipment manufacturer, it has achieved several striking technological merits. One of the recent achievement is Huangling mining company's intelligent unmanned mining technology.

5.3.2 The experience of developing unmanned mining technology

As a coal mining equipment manufacturer, Tiandi has to foster a close relationship with its customers, namely, the coal mines. As a result, whilst Tiandi is the main developer of a whole set of unmanned technology, its user, Huangling Coal Company (黄陵), is also important thus the decision-making process at Huangling will also be presented in order to make this story more complete. In fact, according to the theory of the System of Innovation, the interactions between this system's components are sometimes more influential on the outcome of the system. Therefore, when the actions of equipment manufacturers are under scrutiny, it is always important to bear in mind that the key reason why the manufacturer decides to do so cannot be found if the mining company is ignored. The Tiandi case will be allocated the task of demonstrating these interactions.

Huangling is located in Yan'an, Shaanxi Province, which is to the south of Yulin. It is owned by an SOE, namely, Shaanxi Coal and Chemistry Industry Group. The leading coal mine of Huangling was established in 1989 with a production capacity of six million tons a year. In 35% of the mining area the thickness of the coal seam ranges from 0.8 metre to 1.8 metres. Due to this sharp change in thickness, Huangling's equipment cannot be used to dig coal from this area. Consequently, Huangling mainly focus upon the area where coal seam is thickest. For low-seam mining, the working space is quite limited, there need to be more miners, working conditions are terrible, and labour intensity is high. All these factors can lead to accidents. From early on, the leading Huangling mine faced a vicious circle. Due to the above-mentioned difficulties, if the coal seam is low the production task cannot be fulfilled, the mine has to invest more miners in the hope of finishing the production task on time, the possibility of production accident is even higher, further negatively influencing the accomplishment of the production task. This vicious circle used to baffle the managers of Huangling. They tried every possible solution to solve this problem but without success. In the past, this problem was not a central issue of the company, as it owns high-seam coal mines., But the current management group decided to be first one to eat crab, which means they wanted to risk developing a technology in order to realise an unmanned coal mine, and they wanted to co-operate with a Chinese company. This decision is strategic and once circulated in the company it encountered waves of protest. Those who were against this proposal had good reason. First, some managers thought that developing low-seam unmanned mining technology was not urgent, as the company has sufficient other mining areas to operate and those areas produce a fair profit. Second, some engineers do not trust the Chinese company's technological capability. There had not been any precedents in China that a Chinese company successfully designed and installed unmanned mining equipment, and it would be safer to import foreign equipment. Some workers were afraid of not being able to use the new technology as their education level was not very high, thus they would either be sacked or be paid less. To make matters worse, 2013 witnessed a dramatic downturn in the coal market, and some were afraid that the unmanned technology might only further reduce the company's profit level.

In order to reach a consensus, Huangling's managers' group explained to employees the significance of adopting domestic unmanned mining equipment, both in terms of its significance to the company and its significance to the country. For the company, this task had to be done in due course. It was just a matter of time. After all, the low-seam mining area has to be mined, and it was high time the company invested in the relevant technology to utilise the coal resources buried in the low-seam mining area. It takes years to finish. When the construction was completed, the coal market might be better (this became the case in 2016). For the country, China's coal mining is a labour-intensive industry, which has caused many problems. If Chinese-designed unmanned equipment can be commercialised, a vast market awaited. This kind of propaganda is quite useful for engineers and managers. As for the workers, Huangling made a promise that their salaries would not be reduced and finally persuaded the workers.

No sooner were these psychological barriers removed than the company launched its grand programme. Huangling chose a number of domestic partners, among which Tiandi was one of the main contributors. The No.1 mine was chosen to conduct this experiment. The working face of No.1 mine is 235 metres in length, and 1.1 to 2.3 metres high. This programme was formally launched in January 2013, Huangling investing over 10 million yuan. After a year's effort, it was finished in April 2014, and a month later it passed evaluation by the China National Coal Association. A touching comment on this achievement is that the dream of coal workers to wear white shirts in the mine has been realised. The workers need only sit in front of a computer and all the work can be done with a tap on the keys. This joint venture between Huangling and Tiandi proved to be a great success. The State Administration of Work Safety and the State Administration of Coal Mine Safety jointly issued a document appealing to all Chinese coal mines to learn from Huangling.

According to that document, the lessons we can draw can be summed up as five innovations. First, idea innovation. The new idea liberates the miners from the dangerous environment and strenuous labour input. It also helps to increase the equipment manufacturing level of Chinese companies and promote the image of miners. A typical image of a miner is dirty and brutish, but the new image is clean and tidy. Second, technological innovation. This is also the core concern of this study. Unmanned mining technology faces several challenges, such as how to distinguish rock from coal. In co-operation with Tiandi and other equipment manufacturers, Huangling went to the No.1 mine and in the end designed a set of technology including a one button start and shut down control technology and memory cutting technology. They also designed panorama vision and remote interference technology. Apart from this general technology, technicians invented special coal-cutting technology which can only be applied in No.1 mine. Third, equipment innovation. Fully mechanised equipment is a guarantee for unmanned mining. Huangling chose Tiandi as the main contractor, and ask the company to design the equipment, including the platform and standard design. The final equipment can produce two million tons a year. Besides, all the relevant equipment was linked, all the work from the operation to the maintenance of the equipment can be controlled simultaneously. During the operation of the equipment, 11 technological reforms were completed. This is not only a fully mechanised mining face, but also a fully computerised one. A variety of high technology was used, rendering human intervention, besides providing general instructions and maintenance work, unnecessary. Fourth, management innovation. After the new technology was used, three apparent changes occurred, above all, from underground to ground. Control of all the mining equipment can be finished by ground work, and the relevant payment system and work attendance checking system had been changed. There are far fewer workers now. Normally, only one worker needs to be at the working face to deal with emergencies. Finally, from on-the-spot to remote control. At the outset, some workers still interfered in the production process, but this kind of manual work had been strictly prohibited. Fifth, training innovation is also a means by which the company seeks to fulfil its promise to workers. Only by providing relevant training can the company and the workers achieve a double win. A total of 22 seminars and training courses were organised and 143 workers took part in the training.

Huangling and Tiandi's co-operation has led to a number of improvements. The personnel at the coal face decreased from nine to one and save Huangling five million yuan a year. The accuracy of the coal-cutting and recycle rate have been improved a great deal. The automation rate is over 95%, and all the equipment was produced by a Chinese company. Compared with imported equipment, domestic products save the company almost 30 million yuan.

In 2015, intelligent unmanned mining practice was awarded first prize by the China National Coal Association in the Chinese Coal Mining Science and Technology Advancement competition. Four companies received the prize - Huangling, Tiandi, one of its subsidiaries, Tiandi Marco, as well as Xi'an Coal Mining Equipment Company.

The China Statistical Yearbook on Mining Industry (2013) writes highly of this achievement. At first, this project represented Chinese firms' highest level of technological capability. In this co-operative venture, they tried novel ways to realise automation mining. The yearbook also summarises some lessons we can learn from this project. Above all, the liberation of minds is important. Every innovation entails the ambition of leaders; they need to overcome all the mental and psychological barriers. Second, so-called 'top-level design' is important. Huangling organised a group to be in charge of all matters related to this project, and the project became the firm's strategic target, all relevant resources needing to be supplied when needed. Disaster management and geological guarantees were also decisive. They formed the environment and backdrop of this grand project, and the technologies that were used had to match this environment. Personnel training was the last step Technology and equipment need personnel to operate it. Training current employees will contribute to harmonising labour relations within the company. All these factors convey the message that a technological innovation is by no means a purely technological phenomenon. It is a reflection of all the social relationships behind it and will be better understood when taken as the output of a larger social system.

This breakthrough is path-breaking. It fills a gap in Chinese unmanned mining technology. According to a survey, there are still hundreds of coal mines in China in which miners to do the digging. There are about 900,000 workers working at the coal face. Given the proliferation of unmanned technology, an increasing number of workers may be freed up. Of course, this is by no means a new thing, and its influence should not be overestimated. Numerous mines all over the world owned by global mining giants have realised unmanned operations, but it is the first time that this idea has been tried out in China. This achievement realised remote control on the ground and thus improved the safety conditions of the miners.

Of course, this technology has not matured, it needs to be improved, and needs to be tested in different environments. In this case, the government, to some extent, plays the role of the invisible hand. The regulations and ever-increasing requirement for workers' safety impose invisible pressure on mining companies, and the financial reward one can get by investing in R&D also encourage mining companies and equipment manufacturers to closely co-ordinate with each other. Government and university do not directly interfere but their impact cannot be ignored. A government decision gave birth to this company, and all its initial resources, be they financial or human resources, came from government support. This company used to be a research institute, it still has close links with academic institutions so it is able to get new employees from universities or research institutes. This is an implicit Triple Helix.

5.3.3 The case of Tiandi-Marco Electro-Hydraulic Control System Company

Tiandi-Marco is a subsidiary of Tiandi and it used to be a Joint Venture with Marco. Marco is a German company.[54] In order to find a technologically superior partner, in July 2001 Tiandi decided to co-operate with Marco and establish such a company.

[54] Marco Systemanalyse und Entwicklung GmbH is a German company established in 1982. Its main products include dispensing systems, longwall face mining automation, the VisTwo scada system. See https://www.marco.de/index.php.

Tiandi-Marco (hereafter TM) mainly focuses upon manufacturing hydraulic support control systems, the automation equipment in a mine's mechanised mining system. TM is also the main contributor to Huangling's unmanned mining technology project. From its beginning, TM was established in the hope of learning from a western company and finally possessing the intellectual property right of the core technology. By now, this task has almost been completed, as it is said that TM does not need the technological guidance of Marco and is able to design and produce new products without the assistance of the German company.

The strong technological capability of TM can be traced back to pre-2000. It used to be a subsidiary of the China Coal Research Institute, that is, it was a research institute before being incorporated. Its employees were technicians and had rich experience of doing relevant research in coal mining. Now it has about 335 employees, among which there are two PhDs, 50 Masters, 86 B. As, and 94 Junior College Students. Most of these employees used to work for the China Coal Research Institute. There are five experts getting grants from the State Council.

In 2014 TM was certified as China's Enterprise Technology Centre and became Beijing's High technology enterprise. Just as Haohua did, TM also established a technology centre within the company and has an expert consultation commission as well as a technology commission. R&D investment took up at least 5% of its revenue, and recently this figure has risen to 8%. Apart from this, TM actively applied for funding from the state, the provincial government, and its parent company. In the past three years, it has received a 50-million-yuan research grant. TM tries every means to stimulate its employees' innovation incentives. First of all, it allows its employees to purchase its stock. By now, 32% of TM stock is owned by its employees. Second, TM designs a multi-indicator evaluation system to measure its employees' contributions to innovation, and has designed a multi-level rewarding system. It also co-operates with some renowned universities such as Tsinghua University and MIT.

TM has had a variety of innovation products, the most significant is called SAC Hydraulic Support Electric-Hydraulic Control system. It is a combination of electronic technology, computer technology, and hydraulic support technology. Using an electric-hydraulic control system to manoeuvre a hydraulic support can increase the speed, the degree of automation, the efficiency, and improve the security condition. Meanwhile, it can also reduce manual labour. Compared with using personnel to control the support, SAC can make the movement of the support more accurate thus lead to higher productivity. During the R&D process of the SAC, new technology, new materials, new production process were utilised.

The significance of SAC is that, electric-hydraulic control systems have been adopted by western countries for about 20 years. The technology was not entire new to developed countries, but China could not produce it by itself. The technological success of SAC was soon transferred to a commercial one as it broke the foreign monopoly. Moreover, some of its technological qualities were even better than Marco's products. SAC's information rate[55] is 33.3k, higher than Marco's PM31's 19.2k information rate. SAC's security response time is 300ms, while that of PM31 is 500ms. SAC's service life is about 30,000 times the same as the foreign product. Before SAC was put onto the market, all relevant products were foreign, and were both expensive and difficult to repair as the seller did not have a base in China. SAC can solve these problems with ease. First, the price of the SAC is 40% lower than its western competitors, an imported Electric-Hydraulic Control system product is about 17 million yuan, while SAC's price is only 9.5 million yuan. At present, China has about 1,500 mechanised operation faces, only 200 of which use Electric-Hydraulic

[55] The information rate is represented as an average number of bits of information per second. The rate of 33.3k means SAC can transmit 33.3 k bits every second.

Control, so there is a large market. As a Beijing-based company, TM can provide timely after-sales service, and it can assist its customers to solve all the technical problems much more quickly than western companies. Second, the productivity of a mine can be raised after using the SAC. According to TM’s calculation, an SAC can assist a coal mine to produce half a million tons of coal a year. Finally, the successful commercialisation of the SAC will bring more job opportunities to China and more tax will be generated as a by-product. The SAC was put onto the market in 2008, and in 2010 the China National Coal Association awarded TM first prize in its science and technology advancement competition.

In fact, the significance of choosing this case is not due to its top-level technological capabilities but that it demonstrates Chinese mining machinery makers’ resolution to ascend the value chain and provide a successful story of the trading market for technology policy. It is a success because the technicians at Tiandi were not satisfied with being the pupils of German partners. TM's achievement can be attributed to its sustained commitment to R&D. The import-digest innovation favoured by the Chinese government has been realised by TM, but this realisation never come true automatically. Without continuous investment in innovation, researchers cannot grasp the essence of the product design process, let alone create their own way of doing things. All similar successful stories, for example, the high-speed train, are based on intensive technological learning. Only by learning can a person improve their technological capability as opposed to productive capacity. The success of the SAC is not due to the generous benevolence of Marco, but the result of the active and purposeful technological learning of TM's R&D staff. TM's experience is very valuable. Other Joint Ventures in China need to regard TM as a model if they ever think of developing their own products rather than relying upon foreign partners.

5.4 Conclusion of Case Studies

In this chapter three case studies have been presented. They almost cover a complete industry chain from mining processes to metallurgy, while equipment manufacturing is also included. Based on the three case studies, plus the fourth chapter, we arrive at the following conclusion. The divergence of innovation performance across the different stages of mining is informed by two factors. First, the distance between final products and market or commercialisation, and second, the intensity of interaction between the mining company (including prospecting company and equipment manufacturer) and the university or research institute. To be more specific, the closer the distance and the higher the intensity of the interaction, the better the innovation performance. If one of the two factors do not appear, it is possible that this company's innovation performance is not desirable.

Both the inter-stage difference in innovation and the inter-firm difference in innovation can be explained by the arguments above. Of the different stages of the mining industry, from prospecting to mining, processing and metallurgy, prospecting is the furthest from the market. As we saw in the previous chapter, the final product of the prospecting stage is a kind of possibility or probability. The prospecting company will draw a map which carefully marks the area where there might be valuable mines. But the prospecting company cannot translate its achievement directly into commercial success. In China, the separation of exploration rights and mining rights still restricts the prospecting company to harvesting their own profits. Chinese law discourages the participation of privately owned companies in prospecting. After nearly four decades' Reform and Opening-up, the prospecting stage goes through the least change compared with other mining stages. Besides, scholars and research fellows specialising in prospecting mainly work on theory-building. This reduces the incentive of prospectors to co-operate with academic staff, as these theories can make a contribution to locating a potential mining area, but its contribution is limited. The remaining work will be done by staff engaged in field prospecting. During this process, experience is still more important than theory, at least in China at present. The lack of both factors makes the prospecting stage the least innovative stage in Chinese mining. As for the mining and processing stages, the two are always put together; most mining companies do both mining and processing. The final products of mining can be directly sold to downstream consumers, as is the final product of the processing stage. The distance between the market and mining/processing stage is almost zero. Meanwhile, compared with the prospecting stage, the restriction imposed on private companies by governments is much less, and a great number of private mining companies are active at the mining and processing stages. Mining companies also interact intensively with universities and research institutes, policies encouraging or even stipulating the necessity of industry-university co-operation. Neither a mining company nor a university/research institute can get government funding if it applies for the funding alone and they have to seek a partner in industry or the academic community.[56] This kind of requirement, though arbitrary, produces some desirable outcomes. If you look at the list of awardees of the science and technology advancement competition, you will find that most of the awardees include both mining companies and academic organisations. The mining and processing stages are considered to be the most innovative stages in the Chinese mining industry. The situation at the metallurgy stage is similar to the mining and processing stages, whereas the intensity of interaction between industry and academia is weaker. When it comes to mining equipment manufacturing, its links with academia are even weaker than at the metallurgy stage, leading to criticism of its innovation performance.

The inter-firm difference can also be explained by this theory. For instance, TM's achievements in mining equipment manufacturing are impressive, one reason being that it used to be a research institute. It can realise an internal interaction between

[56] This has not been inscribed in Chinese law, but it has almost become a norm. Some of my interviewees told me that, by finding an academic/business partner (depending upon whether they work for an academic institute or a company), their success rate can be improved.

industry and academia. This kind of internal interaction represent the peak of industry-university interaction. In fact, the technological capability of large SOEs such as Shenhua and Zhongmei is fostered by their in-house R&D, thus they seldom need to seek assistance from outside. The case of Yulin is relevant too. The small semi-coke production factories have little interaction with the academic community, while large companies can seek technological assistance from inside. The other helix, namely, the government, is responsible for shaping different types of interactions between the other two helices. The future development of Chinese mining partly depends upon the adaptation and dissemination of good policies.

The above chapters depict the situation in China. What of other countries? The next chapter will throw some light on this issue.

6. A Cross-Country Comparison

In the mining industry, there are several global giants, representing the highest technological levels in the world. It is useful to compare their business models, the way they do R&D, with their Chinese counterparts. In this chapter, a number of western as well as Chinese mining companies and mining equipment companies will be selected. The criteria of the choice are their ranking in terms of revenue in their own field. It is hoped that this kind of comparison can reveal the differences or the gaps between Chinese mining practice and the practice of global leaders, thus contribute to a better and deeper understanding of the real innovation process in mining companies.

The most important finding of this chapter is that mining companies and mining equipment companies have different innovation patterns. Mining companies mainly engage in process innovation. This kind of innovation entails less investment and results in either a lower cost or a higher output rather than a new product. Mining equipment companies count on product innovation to gain profit. Mining companies tend to have close relationships with academic institutions, while equipment companies tend to rely more upon their in-house R&D sectors. Meanwhile, western companies tend to rely more upon their in-house R&D than their Chinese counterparts, Chinese companies have more intensive interactions with academic institutions

6.1 Innovation in mining companies

Ranking	Names	Revenue（in millions of dollars）	Profit（in millions of dollars）
1	BHP BILLITO	52,267	1910
2	SHENHUA	37,612	1391

3	RIO TINTO	34,829	-826
4	VALE	25,609	-12,129

Table 10： Mining Company Revenue Ranking

According to the Fortune World's 500 largest companies, the four mining companies above were ranked top four among all mining companies. The following section will introduce the innovation process in these companies. Anglo-American will also be introduced, as its ranking follows the above four and I conducted an interview with one of its managers.

6.1.1 BHP Billiton

BHP Billiton is an Anglo-Australian multinational mining, metals, and petroleum company headquartered in Melbourne, Australia. It is the world's largest mining company measured by revenue. In its 2015 annual report, technology and innovation were mentioned a number of times. The main context of doing innovation at BHP is to protect the environment or, in other words, to meet the environment regulations of its hosting countries. The report reads:

> Technology and innovation have the potential to significantly reduce global emissions and meet long-term climate goals…it is vital that low-emissions technologies (LET) are available at scale, lower cost and much faster than the usual commercial time frames to meet the challenge of climate change … Since 2007, we have spent over US$400 million on LET research, development and deployment across a number of projects ranging in scale and complexity. For example, the West Cliff Ventilation Air Methane Project (WestVAMP) first piloted at Illawarra Coal's Appin Colliery in 2001, utilises 20 per cent of available mine ventilation air to produce electricity. This reduces the site's overall GHG emissions footprint by removing the methane from mine ventilation air.

BHP also invests a lot in the development and demonstration of carbon capture and storage (CCS) technologies and became a founding member of CO2CRC, one of the world's leading collaborative research organisations focused on long-term geological storage of carbon dioxide.

There is also a cursory narrative regarding how BHP conducts exploration all over the world which runs:

> Over the past six years, brownfield exploration has increased our reserve base around our portfolio of existing assets in large resource basins, which now provide us with growth opportunities⋯Greenfield minerals (new sites) exploration is focused on advancing targets within Chile, Peru, southwestern United States and is organised through our Copper Business. Greenfield activities include opportunity identification, application for and acquisition of mineral titles, early reconnaissance operations and multi-million-dollar delineation drilling programs.

There is no in-detail description of which kinds of advanced technology BHP utilises in exploration and where BHP bought the technology, equipment, or whether BHP produces the equipment itself.

Year ended 30 June	2015 US$M	2014 US$M Restated	2013 US$M Restated
Exploration expense (1) (2)			
Petroleum and Potash	**532**	544	709
Copper	**90**	111	266
Iron Ore	**38**	56	74
Coal	**20**	29	32
Group and unallocated items	**18**	30	47
BHP Billiton Group	**698**	770	1,128

(1) Excludes exploration expenses from Discontinued operations.
(2) Includes US$28 million (2014: US$72 million; 2013: US$102 million) exploration expense previously capitalised, written off as impaired.

Figure 8：The expenditure of exploration of BHP Billiton

As for other innovations worth mentioning here, this annual report does not give reader a sense that BHP attributes its commercial success to technological innovation. Management innovation might be more important. There is a case study in the report entitled ‘Increased truck performance at Copper's Escondida Mine’. The approach BHP adopts is not technological but through improving operation of its trucks. The report reads: “Escondida benchmarked its truck performance and maintenance activities, both internally and externally, and reviewed how it conducted truck maintenance and shift activities to identify improvement opportunities. A range of initiatives were implemented to improve haul truck production time. Less frequent and larger blasts were used to reduce interruptions to production. Trucks were only taken out of production for preventative maintenance determined by equipment condition, rather than by time in service. The mine also implemented new crib huts and shift relief, called 'hot seating', to keep the trucks moving”.

In short, as the largest mining company in the world, at least by reading its annual report and from surfing on its website, we can see that it gives the impression that innovation does not occupy a core position and, among the four top mining companies, BHP's website is the only one which does not have an independent column for technology and innovation. Whether this reflects the true situation at BHP remains is unclear.

6.1.2 Rio Tinto

Rio Tinto Group is a British-Australian multinational metals and mining corporation with headquarters in London and a management office in Melbourne. Although primarily focusing upon the extraction of minerals, Rio Tinto also has significant operations in refining, particularly refining bauxite and iron ore. Its website provides much more information regarding R&D than the BHP website.

Regarding, mineral exploration, Rio Tinto Exploration is organised into four regional teams, that is, Americas, Australasia, Africa-Europe, and Eurasia. In addition, the Project Generation Group (PGG) provides specialist commodity, data, and information, technical and orebody knowledge assistance to the regional teams. PGG also plays a role in co-ordinating research programmes. Rio Tinto operates the majority of exploration programmes itself rather than outsourcing to others. It will, however, partner readily with smaller exploration companies if this gives Rio Tinto access to attractive opportunities, tenure, local knowledge, or operational skills. Again, this introduction does not include the technologies Rio Tinto employ. In its annual report, there is one small paragraph which states that orebody knowledge and geological expertise are vital in this exploration process and Rio Tinto has a strong tradition of developing and applying innovative technologies to resolve specific exploration challenges. Apart from this, it mentions a Joint Venture between Rio Tinto and Chinalco called The Chinalco Rio Tinto Exploration Company (CRTX)中铝力拓勘探有限责任公司.

Rio Tinto provides exact figures of R&D and innovation. According to its annual report, R&D costs were US$112 million for 2014 (2013: US$231 million), which takes up 0.23% and 0.45% of revenue respectively. Rio Tinto has a Technology & Innovation group (T&I), and its gross costs in 2014 were US$340 million compared with US$370 million in 2013 and US$415 million in 2012. This group delivers values through three levers: 1. Project shaping and delivery: ensuring the Group "does the right projects" and "does the projects right"; 2. Productivity: focusing upon asset performance, technology deployment, and global processes to sustainably improve operations, maximise margins, and capture value, and 3. Innovation: creating step-change improvements to address the significant challenges facing the mining industry. The work of this group is fruitful, and its importance is apparent. Technology and innovation is regarded as an independent business which is parallel to iron ore, diamond exploration etc. The group’s achievements, which also Rio Tinto’s innovation achievements, will now be introduced.

In 2008, Rio Tinto launched a programme called ‘The Mine of the Future’ which has two goals. One is to achieve massive productivity gains in large-scale surface mining, the second is extracting more ore from complex orebodies. By launching this programme, Rio Tinto hopes to create a pipeline of technological innovations through alliances with partners in business, industry, science, and academia. It has used these partnerships to establish six research centres and an innovation centre. This programme has yielded many successful innovation outcomes. Here are some examples:

A. An autonomous haulage system which makes trucks safer and more fuel-efficient. Rio Tinto's iron ore operations in Pilbara, Western Australia manage the world's largest fleet of autonomous trucks. These driverless vehicles deliver their loads more efficiently, minimizing delays and fuel use, and are driven remotely by operators who exert more control over their environment and ensure greater operational safety.

B. An autonomous Drilling System ensuring more effective drilling and better operator safety. Rio Tinto's automated blast-hole drill system enables an operator to use a single console at a location remote from the machinery to operate multiple drill rigs designed by multiple manufacturers. It is much safer for the operators and maximises precision and equipment utilisation. Other innovations which are worth mentioning include AutoHaul ™ (the world's first fully autonomous, heavy-haulage, long-distance rail system), PeakFloat ™ (increases the extraction of minerals by optimizing operating conditions during the widely-used flotation process using a high-performance computer system), a mine automation system (acts like a computer's central processing unit, integrating all automated elements of a mine and optimizing efficient and effective operation), and RTVis ™ (software interprets complex datasets and creates a user-friendly 3D display of a mine for pit controllers, geologists, drill-and-blast teams, mine planners and supervisors).

C. Excellence Centres and an Operations Centres. Rio Tinto has established several excellence centres for data access, expert clusters to enhance productivity etc. Excellence Centres unite experts with those from Rio Tinto's partner organisations, giving them access to real-time data from operations around the world so they do not have to be on-site. These centres enable teams to make better decisions, enhance productivity, and reduce costs. They also improve the safety and wellbeing of employees by reducing the need to travel to mine sites to share expertise and excellence. The Operations Centre is a 'Mission Control' for the entire Pilbara iron ore network located 1,300km to the north. On this site, more than 400 operators analyse data and synchronise an integrated system in real time, managing 15 mines, 31 pits, four port terminals, and a 1,600km connecting rail network. This increases efficiency, improves reliability, decreases variability, and enables the business to better identify and improve performance across the supply chain.

The latest Mine of the Future™ innovation is 'The Processing Excellence Centre' (PEC) in Brisbane. With the aid of a giant interactive screen, technical data is monitored and analysed in real time, enabling processing improvements to be immediately introduced and operational performance to be optimised. A trial phase has already led to various procedural enhancements, such as adjusting the flotation process which has increased the recovery of copper and gold at Oyu Tolgoi in Mongolia.

Not satisfied with its own innovation resources, Rio Tinto is currently looking for innovation partners. In 2013, The University of Nottingham and Rio Tinto agreed a £6 million, five-year partnership to deliver the next generation of innovative technologies for the mining industry. Engineers at the University have been carrying out research focusing upon new ways of separating ores based on the properties of individual rocks, meaning that waste material with no valuable minerals contained within it can be rejected prior to energy-intensive further processing.

All in all, innovation at Rio Tinto covers a wider range and plays a more important role than that at BHP, at least according to their annual reports and the structure and formation of websites. Furthermore, based on the innovation undertaken by Rio Tinto, a significant conclusion can be drawn, namely, that innovations in mining follow obvious logical trajectories, reduce the unit cost of production, increase productivity, and make sites safer. The main tools are automation, computerisation, and remote control etc. This trend might represent the direction of development for mining companies all over the world.

6.1.3 Vale

Vale SA is a Brazilian multinational diversified metals and mining corporation and one of the largest logistics operators in Brazil. In addition to being the fourth largest mining company in the world, Vale is also the largest producer of iron ore, pellets, and the second largest producer of nickel. As at Rio Tinto, innovation and technology is an independent sector at Vale.

Surprisingly, as a mining company in a developing country, Vale leave the impression that it attaches more importance to innovation than its counterparts in the developed world. This conclusion is borne out by the following facts and figures.

Primarily, compared with Rio Tinto, the ratio of R&D over total revenue at Vale is higher. Revenue in 2010 and 2011 stood at US$46,481 million and US$60,389 million respectively, while investment in R&D stood at US$1,136 billion and US$1,986 billion. The ratio was 0.28% and 0.33%. In 2014, Vale’s revenue was US$37,539 million and R&D investment stood at US$0.9 billion, which accounted for 0.27% of total revenue. Its commitment to innovation matches that of Rio Tinto.

Meanwhile, the Vale Institute of Technology (ITV) is an independent institute specialising in innovation It was founded in 2009 with the aim of seeking medium and long-term innovative solutions that contribute to improving the operational performance of every stage of the company's business, from the mine to the final delivery of product to clients. Since it was created, the Institute has entered into 97 R&D agreements, provided more than 50 research scholarships, and created partnerships with 36 Brazilian and international institutions, including Brazil's agricultural research institute, Embrapa, the National Council for Scientific and Technological Development (CNPq), the Massachusetts Institute of Technology (MIT), and the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. The ITV operates by integrating research, teaching, and entrepreneurship. Regarding the first, the idea is to promote fundamental scientific and technological knowledge in mining and sustainable development. Vale has three large laboratories, which are responsible for developing technological solutions for its mining projects. Two are located in Brazil - the Mining Development Centre (CDM), and the Ferrous Metals Technology Centre (CTF) - while the third, Vale Technical Services Limited (VTSL), is in

Canada. Established in 1965, CDM was responsible for the first major technological advances made by Vale, as it developed new technology for processing low-grade iron ore, raising the lifespan of Vale's mines, and assisting the company to arrive at its current position as the world's second largest mining company. Vale's oldest research centre, VTSL, is a global leader in nickel technology. At CTF, Vale conducts research into iron ore-related production processes, from extraction up to the manufacture of steel products. Using physical and statistical simulations, VTSL's researchers test a wide range of processes, from different ore processing techniques to the behaviour of ore in steel mills.

Regarding the second, VTSL aims to train professionals who are capable of confronting the challenges facing global mining in the 21st century in a scenario of increased concern for sustainability. In Belém, the ITV offers a professional Master's degree in the sustainable use of natural resources in tropical regions, which is currently in its third edition. Recognised by the Brazilian Ministry of Education's Graduate Education Support Agency (CAPES), this post-graduate course is the first of its kind to be offered by an institution linked to a company in the mining sector. The aim of the Master's degree is to train professionals to be able to deal with issues related to the sustainable use of natural resources and attract and develop talented workers with skills in the area of mining. The course lasts for two years. In Ouro Preto, the ITV has put together two specialisation courses on open-pit mines and ore treatment. Both have been offered to Vale professionals since the second half of 2015. The third pillar of the ITV's activities is entrepreneurship, which aims to encourage the training of researchers and business owners so they can lead technology-based companies in Brazil.

Some projects developed by ITV can be found on Vale's website. One of them is 'Monitoring'. Created by researchers from the ITV's Climate Change Research Group in Belém, the East Amazon Weather Forecast System, or Forecast Network, publishes daily weather forecasts that assist in the planning of actions by reducing the impact of extreme meteorological events. This tool, which is the first of its kind entirely developed by a private company in Brazil, monitors weather conditions and climate in the regions where the N4 and N5 iron ore mines are located at Carajás.

To sum up, Vale is an innovative mining company, as its website demonstrates.

6.1.4 Anglo-American

Anglo-American Plc is a multinational mining company based in Johannesburg, South Africa and London, the UK. It is the world's largest producer of platinum, responsible for around 40% of world output. It is also a major producer of diamonds, copper, nickel, iron ore and metallurgical and thermal coal.

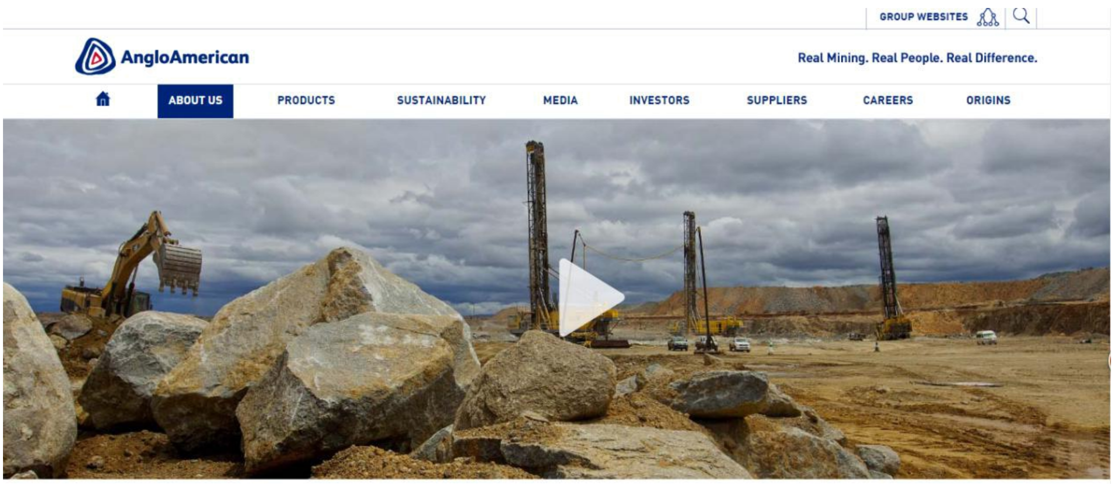


Figure 9：The home page of Anglo-American

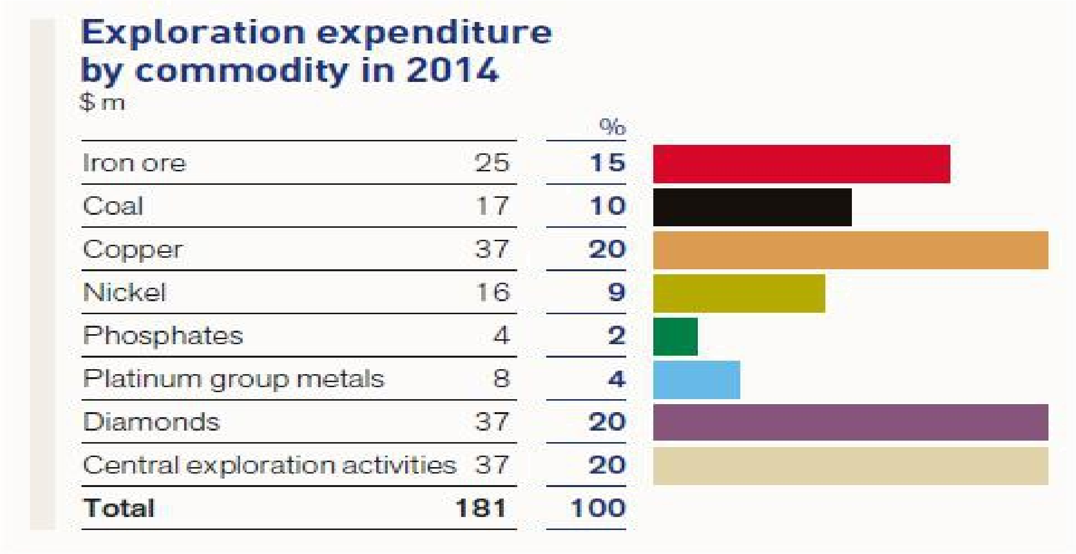
The above picture shows the Anglo-American home page Like BHP, it does not have an independent section for R&D or technology or innovation. In its annual report, I did not find a section regarding innovation either.

Generally speaking, the impression Anglo-American leaves is similar to that of BHP. They attach more importance to management innovation in their annual report. They seldom mention innovation specifically, which means they do mention technology or innovation but only together with other corporate goals.

In the 2013 and 2014 annual reports, Anglo-American point out that its strategy is delivery, which means delivering the returns the company's shareholders expect but doing so in a way that creates shared value for all the partners and stakeholders of the company. In order to achieve this strategy, Anglo- American propose a programme entitled 'Driving Value' in the hope of reshaping the management structure of the company.

Anglo-American boasts its diversity and its portfolio is diverse in three ways. The commodities and minerals they mine, the range of countries they operate in, and that the commodities and minerals they mine cover all stages of the economic cycle. This approach is designed so that Anglo-American can shield itself through economic downturns and industry turbulence and means it has more balanced exposure to political and currency risks. Its value chain is also diverse. Anglo-American operates across the entire mining value chain – from exploration through to marketing. Although it focuses upon resource development, mining, and operations, it is developing other areas of the value chain, e.g. its marketing capabilities, where it can see opportunities to deliver increased value.

The two reports also contain figures in relation to the exploration activities conducted by Anglo-American. According to the report: "Global exploration activity for 2014 concentrated on greenfield projects across a number of mature and frontier locations, as well as on adding value, through increasing resources and reserves, to our operations and advanced projects across all our commodities. Exploration expenditure for the year amounted to $181 million (2013: $207 million) and spanned 19 countries”.



Exploration expenditure by commodity in 2014
$ m

	$ m	%
Iron ore	25	15
Coal	17	10
Copper	37	20
Nickel	16	9
Phosphates	4	2
Platinum group metals	8	4
Diamonds	37	20
Central exploration activities	37	20
Total	**181**	**100**

Figure 10: Anglo-American’s exploration expenditure, 2014

Whilst innovation and R&D do not have an independent section in the annual report, there are short paragraphs which discuss innovation and technology.

First, the Chairman's statement in the 2014 annual report mentioned innovation. This section is called Developing and Deploying New Technologies. It recalls that, in the past, Anglo-American, deservedly, had a reputation for being a leader in mining technology, Today, however, no mining company can work wholly within its own silo, therefore Anglo-American works with a range of global institutions and universities in the Americas, Australia, South Africa, and the UK to support the company in its drive to be at the forefront of mining technology. The Chairman states that the company seeks to move on to the next phase, with developments such as rock-cutting lasers, alongside the deployment of digital engineering that can simulate mine and infrastructure conditions prior to the first shovel being put in the ground. In turn, the adoption of the latest construction techniques will greatly reduce the labour intensiveness and development risks of projects.

The three Ps, namely, portfolio, people, and performance, play a pivotal role in Anglo-American's business model. Innovation is performed by people, so in the 2014 annual report, one small paragraph in the introduction to the company's business model was devoted to intellectuals. It runs: ‘We aim to drive aggressive innovation to support consistent over-delivery on commitments. We link our technical and marketing knowledge to ensure we invest our efforts in the key leverage points in the “mine to market” value chain.'

Anglo-American has a programme entitled ‘Future Smart Mining’. The De Beers Group is leading a research project that aims to deliver carbon-neutral mining at some of the company’s operations in as few as five years. The project aims to accelerate what is already a naturally occurring and safe process of extracting carbon from the atmosphere and storing it at a speed that could offset man-made carbon emissions. The project has seen the creation of the Rapid Mine Development System (RMDS), together with Atlas Copco, designed to develop low-profile tunnels in hard rock. The company fitted trucks at Sishen iron ore mine in South Africa with tracking radars for object detection, in-cab operator display, collision detection alarms, and auto-braking technology. The Future Smart Mine programme also tries to harness the power of sound and recycle more water. In short, this reflects how Anglo-American decides to turn to technology to weather economic downturns.

6.1.5 Shenhua

Shenhua was the second largest mining companies in terms of annual revenue in 2015. According to Nolan (2001b, p 734):

> The Shenhua project grew out of several sets of influences. Shenhua’s production base is Shenfu Dongsheng coalfield which provides reliable low cost and high-quality coal. Moreover, a combination of the large size of the deposits and the high quality of the coal provided an opportunity for China to develop a competitive international supplier of steam coal.

The main problem is its remoteness. The state has had to invest a large sum of money to construct a dedicated rail link and port facilities. Following the completion of Shenhua’s construction, it became a flagship company of the Chinese mining industry.

Shenhua Group was founded in October 1995 under the auspices of the State Council of the PRC. It is the largest coal-producing company in China. In 2014 Shenhua Group produced 437 million tonnes of coal and sold 588 million tonnes of coal. In 2014 its revenue was 328.6 billion yuan (US$53 billion), and the company ranked 196th in the Global Fortune 500. The same year, Shenhua Group's profit was 64 billion yuan (US$10 billion).

Shenhua's core business can be divided into four parts, that is, coal, power generation, coal chemicals, and transportation. These business segments constitute a relatively complete value chain. Based on the profits from operations of all business segments before eliminations upon consolidation under the International Financial Reporting Standards, the percentages attributable to the coal, power, transportation, and coal chemical segments were optimised to 41%, 31%, 26%, and 2% respectively in 2014 from 50%, 26%, 22%, and 2% respectively in 2013.

In Shenhua's annual report for the financial year 2014, the Chairman proposed the concept of innovative development. In his statement he stated: 'To emphasise the concept of innovative development, the Group's R&D expenditures in 2014 amounted to US$173.2 million with the dollar versus RMB exchange rate being 6.2, with the smooth progress of a series of key scientific and technological innovation projects including green exploitation of coal mines as well as the initiation of a series of major projects including heavy-haul railway technology, indicating technological innovation has become a fundamental support for the development of the Company'.

Compared with its global competitors, at least superficially, Shenhua attach equal importance to innovation. This conclusion is borne out by the following figures.

R&D expenditure in the period	60.5m dollars
Capitalized R&D expenditure in the period	112.7m dollars
Total R&D expenditure	173.2m dollars
Percentage of total R&D expenditure to revenue (%)	0.4

Table 11: R&D expenditure of Shenhua, 2014

Source: http://www.csec.com/uploadfiles/shenhua_china_en/1441961641237.pdf.

The total R&D expenditure of Shenhua Group in 2014 amounted to US$173.2 million, which was mainly attributable to the Group further strengthening the clean utilisation of coal as well as on green mining, ultra-low emission of coal-fired generators, digital mines, comprehensive use of coal ash after combustion, and heavy-loaded railways. The increase in R&D investment is consonant with the Group's strategic principle of promoting the development of clean energy, which enables it to enhance its core competitiveness and its ability to maintain sustainable growth.

Operational indicators	Unit	2014	2013	YoY Change (%)	2012 (restated)
(I) Coal					
1. Commercial coal production	Million tonnes	**306.6**	318.1	(3.6)	304.0
2. Coal sales	Million tonnes	**451.1**	514.8	(12.4)	464.6
Of which: Export	Million tonnes	**1.6**	2.7	(40.7)	3.3
Import	Million tonnes	**6.9**	15.2	(54.6)	10.7
(II) Power generation					
1. Gross power generation	Billion kwh	**214.13**	225.38	(5.0)	207.90
2. Total power output dispatch	Billion kwh	**199.44**	210.18	(5.1)	193.46
(III) Coal chemical					
1. Sales of polyethylene	Thousand tonnes	**265.5**	262.4	1.2	267.7
2. Sales of polypropylene	Thousand tonnes	**268.1**	267.9	0.1	277.6
(IV) Transportation					
1. Turnover of self-owned railway	Billion tonne km	**223.8**	211.6	5.8	176.2
2. Seaborne coal	Million tonnes	**235.8**	227.3	3.7	203.2
Of which: At Huanghua Port	Million tonnes	**131.6**	127.4	3.3	95.6
At Shenhua Tianjin Coal Dock	Million tonnes	**36.6**	31.1	17.7	28.8
At Shenhua Zhuhai Coal Dock	Million tonnes	**5.8**	1.5	286.7	0
3. Shipping volume	Million tonnes	**87.7**	118.6	(26.1)	97.7
4. Shipment turnover	Billion tonne nautical miles	**72.2**	114.9	(37.2)	82.5

Figure 11: Operational data of Shenhua,2014 exports, imports.

Source: Ibid.

Shenhua's capacity to innovate has been advancing progressively. In 2014 a series of industrial technologies and scientific research projects, including digital mines, critical technology for the protection of groundwater and surface ecology in modern coal mining, ultra-low emission of coal-fired power generators and critical technology for heavy-loaded railway have achieved significant progress. During the reporting period, the group was granted 400 patents, 78 of which were for inventions.

The number of technical staff at Shenhua is also significant. A figure of 10,083 out of

92,738 employees are technical workers, 11 % of the total work force.

Shenhua has been chosen as the operator of a coal liquefaction programme. Coal liquefaction is a technology by which coal is transformed into oil under high temperatures, high pressure, and hydrogen (Nolan, Shipman & Rui, 2004). This project was initially negotiated between the USA and China. Shenhua's advantages in relation to a coal liquefaction project include the excellent condition of its natural resources, advanced equipment and management, the location of Shenhua's coalmines in an area of severe oil shortage etc.(Ibid). The coal liquefaction project has gained great success. It is the largest coal liquefaction plant in the world and every year these plants process several million tons of coal and produce several million oil-related products.

If the four largest mining companies were put together, the two from the developing countries are more committed to innovation, while the two from developed countries do not publish sufficient information about innovation.

Combining the five mining companies, we find that western companies choose their business strategy based solely on commercial considerations, feeling freer to adopt automation and mechanisation. Their Chinese counterparts, however, face complicated challenges. The global giants began their global exploration much earlier than Chinese companies, and most of the 'Tier 1' mines have been discovered. Only high tier mines can utilise heavy mining equipment. Neither do Chinese mining companies have a business environment to implement strategy based on pure commercial logic or a proper geological environment to develop heavy mining equipment. Consequently, the degree of automation is relatively low in China. Ben Fine mentions a phenomenon in 1930s England: "the introduction of the best technology, namely cutting by chain machine, proceeded at a much greater pace than mechanisation itself" (Fine, 1990, pp97). China faces the same question. Large mines might be able to employ state-of-the-art technology, at the same time, however, some small mines are still quite labour- intensive.

6.2 Mining equipment manufacturing companies

Mining equipment manufacturing companies offer mining companies the tools they need to undertake mining. Such companies rely more upon R&D thus invest more in technological innovation. As in the previous section, three foreign companies and one Chinese company will now be introduced.

6.2.1 Caterpillar

Caterpillar Inc. is an American corporation which designs, manufactures, markets, and sells machinery, engines, financial products, and insurance to customers via a worldwide dealer network. Caterpillar is the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines, and diesel-electric locomotives. Innovation is at the core of Caterpillar's business as can be seen by looking at its website and the figures. The consolidated sales and revenues (in millions) from 2010 to 2014 were US$42,588, US$60,138, US$65,875, US$55,656, and US$55,184 respectively. Expenditure on R&D can be seen in the table below. This ratio is over 10 times those for mining companies. As a result, there is more information on innovation on the Caterpillar website. This is not surprising, at least in hindsight. After all, the products of mining companies are minerals, which are not the direct outcome of innovation, whereas the products of equipment companies are mining machinery which must emerge from R&D. The differing natures of these two kinds of companies explain the contrasting roles technological innovation plays.

	R&D(€million)	Sales(€million)	R&D Intensity
2012	1869	49,928	3.7
2013	1483.6	40,356.8	3.7
2014	1758.5	45,452.6	3.9
2015	1988.6	43,180.9	4.6

Table 12: The ratio of R&D investment at Caterpillar compared with sales

Source: http://iri.jrc.ec.europa.eu/scoreboard.html.

Compared with Rio Tinto and Vale, innovation occupies a more apparent position on the Caterpillar website. Innovation only occupies a sub-section of the Rio Tinto and Vale websites. One has to choose ‘Our Business' in order to find technology and innovation at Rio Tinto or choose ‘Press' at Vale's, while it is at the centre of the Caterpillar home page.

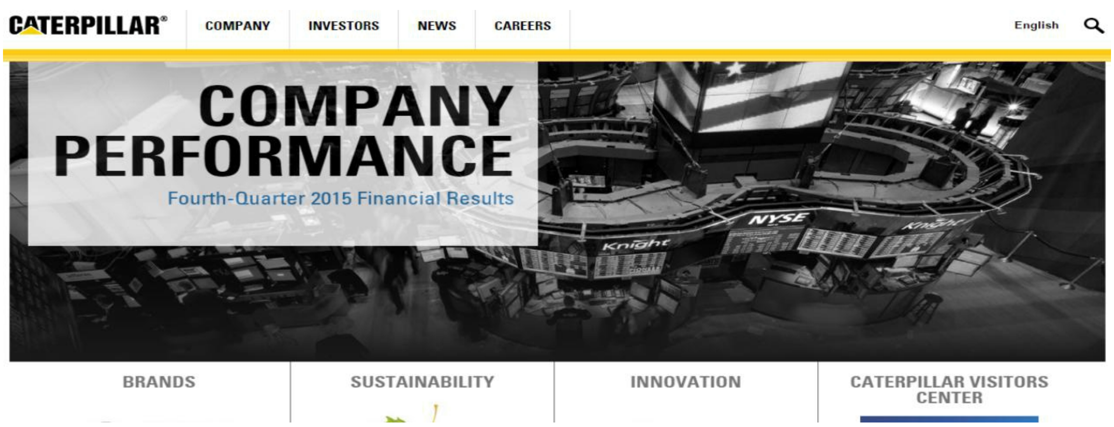


Figure 12: The Caterpillar Homepage

Caterpillar's innovation section is divided into four parts, that is, Caterpillar Ventures, Technology Licensing, Research & Development and Customer Solution.

Caterpillar Venture Capital Inc. (Caterpillar Ventures) assists entrepreneurs around the world to grow and scale their businesses by leveraging Caterpillar's industry expertise, supply base, and independent dealer network. Caterpillar Ventures focuses upon areas of investment including distributed power, analytics, robotics, additive manufacturing, and business models that help its customers be successful. Caterpillar Ventures is a wholly owned subsidiary of Caterpillar Inc. One of its latest investments is in Cottonwood Technology Fund, which focuses upon technology-related businesses, in particular, chemistry/material sciences, photonics, biosciences, and new energy related.

Technology licencing is about the protection of intellectual property. If a customer wants to use Caterpillar's technologies, they apply to Caterpillar to evaluate the ideas, become connected with the appropriate group within this enterprise, and develop the appropriate agreement.

Caterpillar employs more than 11,000 engineers and over 350 PhD-level scientists and technology experts. It holds more than 15,000 active patents and manufacture its products on nearly every continent. It has R&D centres in America, Japan, China, and the UK. It also has partnerships with industry, government, and academic institutions around the world, such as NASA, DARPA, the European Union Research Executive Agency, and Innovate UK.

In the Customer Solution section, Caterpillar provides three approaches to assist its customers. They are technology, data analytics, and autonomy. The technological strategy focuses upon four themes - Energy and Transportation, Machines and Machine Systems, Automation and Enterprise Solutions, and Factory Technology Solutions. Research activities currently underway within these areas include efforts to improve fuel consumption and reduce greenhouse gas, reduce owning and operating costs, increase uptime, increase operator efficiency, enable remote, autonomous, and semi-autonomous operations, bring novice operators to skilled levels, further extend commonality, increase worksite efficiency, increase power density, and expand dual fuel and natural gas solutions. On the website, six technologies creating customer solutions are introduced. Minestar aims to help the customer manage five kinds of challenges from improving productivity to improving safety, lowering costs, meeting sustainability goals, and integrating automation. The capability sets — Fleet, Terrain, Detect, Health and Command — can be used in combination or individually. Many products in this group have something to do with automation. As is widely recognised, the increase in mining activity worldwide has depleted the existing pool of mining workers. At the same time, up to half the global work force is currently over the age of 50 and expected to retire in the next 10 years. And as mines move into more remote areas, it becomes even more difficult to find qualified people willing to operate equipment in these rugged environments. Under such circumstances, automation becomes attractive to mining companies. Caterpillar produce various kinds of automation products, e.g. autonomous trucks. Cat Connect makes good use of technology and services to improve customer jobsite efficiency. Using the data from technology-equipped machines, customers gain more information and insight into their equipment and operations. The website introduces two ways of achieving this goal. One is through improving efficiency. By monitoring production in near real time, the customer gets the information and guidance they need to get more work done, in fewer passes and with less guesswork.

Caterpillar's acquisition of Bucyrus should not be ignored. Bucyrus-Erie was an American surface and underground mining equipment company. It was founded as Bucyrus Foundry and Manufacturing Company in Bucyrus, Ohio in 1880. Before the acquisition, it manufactured electric mining shovels, hydraulic shovels, drills, walking draglines, trucks, and high-wall miners for the surface mining industry. In addition, Bucyrus makes Original Equipment Manufacturer (OEM) parts and provides support services for all Bucyrus machine brands. It is also a supplier of solutions for underground coal mining including longwall equipment, and an extensive line of room and pillar products. Bucyrus supplies equipment from hydraulic shield supports, electro-hydraulic controls, conveyors, ploughs and shearers, to crushers and diesel transport vehicles. It maintains a global network of company-owned sales, repair, and maintenance centres in key mining regions around the world. The company also maintains a continuous presence at certain customer sites internationally. One of its star products is the 8200 dragline, one of the biggest draglines in the world.

There is very little overlap between Bucyrus product lines today. The Bucyrus product line is highly complementary to the Cat product line. Caterpillar is known for its trucks and earth-moving equipment, while Bucyrus's draglines and underground coal mining machinery are common sight on building sites.

Caterpillar claims that: 'The acquisition is based on Caterpillar's key strategic imperative to expand its leadership in the mining equipment industry, and positions Caterpillar to capitalise on the robust long-term outlook for commodities driven by the trend of rapid growth in emerging markets'. The transaction was valued at approximately US$8.6 billion (including net debt). The timing of this transaction is worth mentioning. Negotiations began in 2010 and finished in 2011. The world mining industry, as well as the Chinese mining industry were at the end of their heyday at the time. In hindsight, it can be seen that this acquisition was a means of demonstrating Caterpillar's resolution to expand its product ranges and services in mining. The purchase complete, Caterpillar dropped the name 'Bucyrus', meaning that most of the mining equipment being produced by Caterpillar is in fact contributed by former Bucyrus engineers or workers. Another driving motivation for the transaction is that Caterpillar predicts that more than US$400 million in annual synergies derived from its mining equipment businesses from 2015. Synergies might include the following: 1. Market leading sales and support capabilities of Caterpillar dealers and a broad, one-stop shop for global mining customers; 2. Caterpillar remanufacturing products and services for Bucyrus equipment; 3. Caterpillar engines and components to enhance performance and lower owning and operating costs for Bucyrus equipment; 4. Additional scale and cost efficiencies in areas such as purchasing and engineering; 5. Deployment of manufacturing best practices through the Caterpillar Production System.[57]

This transaction, however, was under the shadow of the downturn in the mining industry soon after its completion. In 2015 Caterpillar announced that it would cut several thousand jobs due to the miserable prospects in the mining industry. It remains to be seen whether this acquisition will be fruitful.

To sum up, as the world's largest construction equipment producer, Caterpillar demonstrates its strong motivation and commitment to innovation and produces a wide range of technology-intensive products. The videos on the website articulate Caterpillar employees' awareness of the pivotal role of innovation in the survival of their company.

6.2.2 Komatsu

Established in 1921, Komatsu Ltd. is a diversified provider of industrial-use products and services. While remaining an international leader in the field of construction and mining equipment, the company engages in other businesses, such as industrial machinery and vehicles, logistics, electronics and other solutions-based operations. It is the second largest construction equipment manufacturer in terms of its

[57] http://www.prnewswire.com/news-releases/caterpillar-to-acquire-bucyrus-creating-mining-equipment-company-with-unmatched-product-range-unrivaled-customer-support-highly-complementary-combination-expected-to-drive-strong-synergies-108134769.html viewed on 2017-3-24.

consolidated revenue and market share.

Komatsu has a business strategy entitled ‘Growth Strategies Based on Innovation'. This strategy leads its focused efforts in the ‘Together We Innovate GEMBA[58] Worldwide’ mid-range management plan.

On the Komatsu website, innovation is defined as to “create and offer new value designed to streamline our customers' business in the domain of solutions by getting deeply involved in their jobsite operations in collaboration with their distributors and suppliers.” In addition to the domains of products and service, Komatsu proudly displays the advanced technology it possesses on its website. Examples include slant-nosed dozer design, hydrostatic drive and steering in small and mid-size bulldozers, hydrostatic transmission, viscous dampers mounted on cabs, trailing arm type front suspensions, and the lock-up torque converter.

Komatsu’s R&D has yielded a number of outcomes:(1) Hybrid technology. Komatsu has launched a new product, the HB205-1 Hybrid Excavator. It is environmentally friendly; (2) the Intelligent Machine Control (IMC) system. This system is designed to let operators focus upon moving material efficiently - from bulk excavation to final trim - without having to worry about over-excavation or damaging the target surface - resulting in significant improvements in efficiency and productivity compared with conventional construction processes. Komatsu’s product PC210LCi-10 truck, designed with IMC, won a 2015 Innovation award as it can reduce the construction time to a large extent, has an intelligent semi-automatic control system which empowers the operator so that they do not have to rely upon people outside the machine to tell them whether they are on grade, and they have less tunnel vision than if they

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58 Japanese word for ‘the real place’.

constantly need to look at a machine guidance monitor.

Komatsu not only provide products but also offer what they call ‘Dantotsu’ (Japanese for ‘try to be better than best’) service and solutions. According to Komatsu's sustainability report, the driving force of its innovation is “to thoroughly understand our customers’ jobsite operations”, the second driving force is: “to capture promising technologies for the future, particularly in the field of ICT”. Komatsu created the Office of Chief Technical Officer in April 2014. As part of its drive to strengthen collaborations with academia and industries, in 2015 Komatsu made itself an equity participant in ZMP Inc., Japan's leading company in image processing, sensing, and control of the Advanced Driver Assistance System. It also reached an agreement with the Tokyo Institute of Technology in a multiple range of fields, such as materials, telecommunications, and measurement.

One Dantorsu service Komatsu offers is the KOMTRAX (Komatsu Machine Tracking System) Plus machine management system for mines. This is a fleet management system for large equipment for use in mining, which enables the client to obtain detailed information concerning the condition of machines via satellite communications. Komatsu and distributors can analyse ‘vehicle health’ and other operating conditions and provide the information to jobsites using the Internet from a remote location on a near-real time basis. As a result, customers can receive vehicle maintenance in a timely way to avoid major technical trouble, thus reduce their maintenance expenses and downtime costs. As for other solutions, Komatsu provide an Autonomous Haulage System for construction equipment, an intelligent machine- controlled dozer equipped with automatic blade control functions, to name but two.

	R&D(€million)	Sales(€million)	R&D Intensity
2012	532.3	16506.9	3.2
2013	444	13453.2	3.3
2014	482.8	13509.2	3.6
2015	539.2	14158.6	3.8

Table 13: The ratio of R&D investment at Komatsu compared with sales

Source: http://iri.jrc.ec.europa.eu/scoreboard.html.

Komatsu's mining division designs, manufactures, and supports equipment supplied to mining customers. The products include excavators/shovels, dozers, wheel loaders electric trucks, and Mechanical trucks. In addition to providing equipment, Komatsu America Corp. includes Modular Mining Systems, the capstone of its mining tool portfolio. Modular supplies data-driven mine management solutions. It also supplies the site supervision system for Komatsu's Autonomous Haulage System (AHS), the world's first commercial autonomous mining haulage system, operating a production fleet of driverless mining trucks.

Like Caterpillar, Komatsu is also considering taking advantage of acquisition to grow. Its target is Joy Global, which will be introduced in the next section. This transaction is valued at US$3.7 billion. Komatsu's main mining equipment plant is based in Peoria, Illinois, US, which makes it an easy fit with Joy Global. After the acquisition is complete, Joy Global will become a consolidated subsidiary of Komatsu. The deal, Komatsu's biggest ever acquisition, is set to boost its ability to compete with Western rivals, in particular, Caterpillar. Compared with Caterpillar, Komatsu chose to launch its acquisition at the trough years of the mining industry, which could lower the cost of this transaction. The new Komatsu company will remain the strongest competitor of Caterpillar. Currently, Komatsu only makes surface-mining equipment, while Joy is the largest independent manufacturer of machines used underground.

Based on the information on its website, we can conclude that Komatsu has similar innovation content and features as Caterpillar. The amount of money they invest in R&D and their products cluster resemble each other.

6.2.3 Joy Global

Joy Global deserves attention because it specialises in manufacturing mining equipment, while other giants in this industry have much wider product menus.

Joy Global Inc. is a leading manufacturer and servicer of high-productivity mining equipment for the extraction of coal and other minerals and ores. It manufactures and markets original equipment and parts and performs services for both underground and surface mining, as well as certain industrial applications. Its equipment is used in major mining regions throughout the world to mine coal, copper, iron ore, oil sands, gold, and other minerals. It operates in two business segments, that is, Underground Mining Machinery and Surface Mining Equipment. Joy Global is a major manufacturer of underground mining machinery for the extraction of coal and other bedded minerals and offers comprehensive service locations near major mining regions worldwide. It is also a major producer of surface mining equipment for the extraction of copper, coal, and other minerals and ores, and provides extensive operational support for many types of equipment used in surface mining. Its principal manufacturing facilities are located in the United States, including facilities in Alabama, Pennsylvania, Texas, and Wisconsin, and internationally, facilities in Australia, Canada, China, South Africa, and the UK. This narrative can be clearly seen on the Joy Global website.

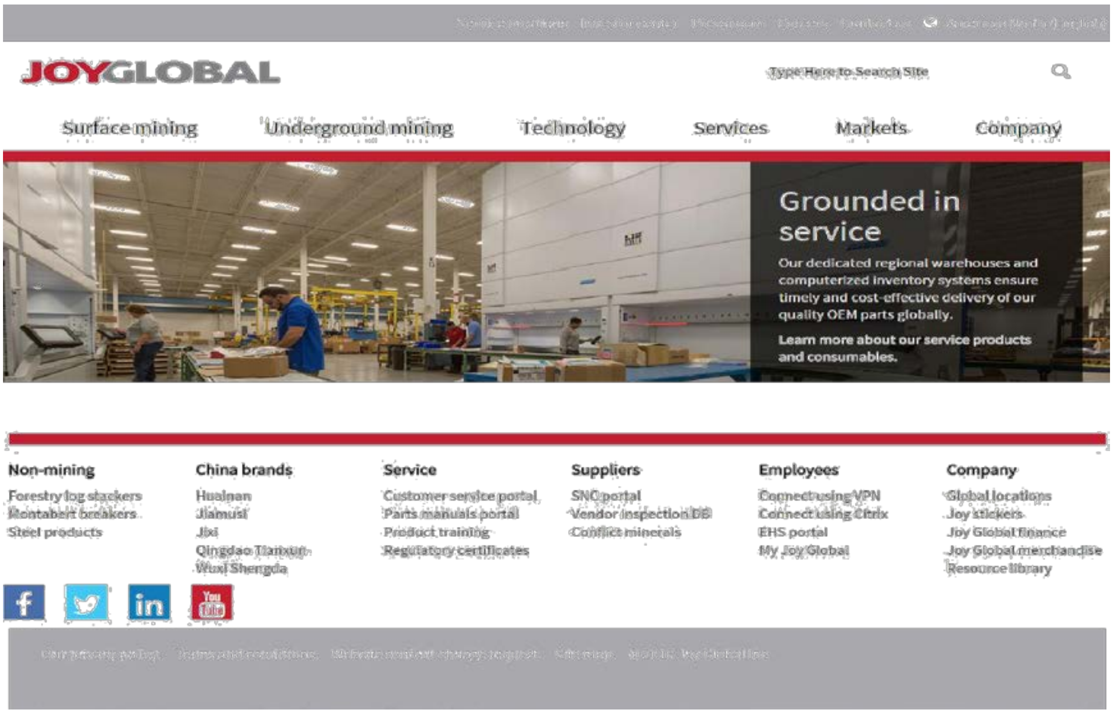

Figure 13: The homepage of Joy Global.

Interestingly, Joy Global's website places its Chinese market at such a core position that we find an independent China brands section. Joy also runs a Chinese website. In fact, all mining companies and mining equipment companies care about the Chinese economy very much. Almost all of their annual reports mention China and use China's economic downturn as a reason to explain their business recession.

Joy Global's underground mining business belongs to Joy Mining Machinery, an operating subsidiary of Joy Global Inc. Its products and services include armoured face conveyors, battery haulers, continuous chain haulage systems, continuous miners, conveyor systems, feeder breakers, flexible conveyor trains, hard rock mining products, high-angle conveyors, longwall shearers, powered roof supports, roof bolters, shuttle cars, life- cycle management, project management, 'smart services' (a full-service support that gathers relevant information in real time and uses it to deliver services that are pre-emptive and predictive, which enables customers to maximise the productivity and value of their assets by providing better machine availability, utilisation, and reduced costs. The services include equipment monitoring, predictive diagnostics, service training support and parts management). Joy Global's personnel and distribution centres are strategically located close to customers in major mining locations around the world.

Joy Global's surface mining business belongs to P&H Mining[59]. P&H Mining's products and services include blasthole drills, conveyor systems, electric mining shovels, feeder breakers, high-angle conveyors, walking draglines, wheel loaders, and life-cycle management. In addition, it also offers project management and 'smart services'. P&H's brochure announces that: "In nine out of ten surface mines you will find powerful, smart, highly productive and reliable digging and drilling machines bearing a familiar black-and-yellow 'P&H' trademark. The sun never sets on that trademark". The company used to produce construction equipment too, but it sold its construction equipment product line in 1988.

Aside from these machines, Joy Global is developing Joy Global Business Systems (JBS) to promote competitive advantage throughout the company by implementing programmes beyond its factories and service facilities to all company functions. It is also taking its JBS Operational Excellence processes and principles to mines to help customers eliminate waste, simplify their processes, drive to automation, and ensure safety.

Joy Global has some successful merger and acquisition recently. For example, in 2014 it acquired Mining Technologies International (MTI), a Canadian company specializing in underground hard rock mining machinery. This acquisition is an important

59 Pawling and Harnischfeger, the founders of Joy Global Equipment, an operating subsidiary of Joy Global Inc.

milestone in executing Joy Global's strategy of expanding into non-coal markets. During the fiscal years 2011 and 2012, Joy Global completed a series of transactions that resulted in its acquisition of International Mining Machinery Holdings Limited (IMM,国际煤机集团), a leading designer and manufacturer of underground mining equipment in China. IMM's operations are included in Joy Global's underground segment. Actually, Joy Global conducted this acquisition in order to expand its Chinese market. Under the title 'China brands' on Joy's website four locations, namely, Huainan, Jixi, Jiamusi, and Qingdao used to be part of IMM. Joy Global acquired IMM's business in these cities by purchasing IMM itself. In 2015 its acquisition of Montabert gave Joy Global a solid portfolio of leading rock breaker and drill products as the company accelerated its growth in the hard rock and industrial mineral markets.

Innovation plays a vital role in Joy Global's business success. In its annual report, writers use the expression 'move the needle' to describe innovation and, naturally, the company includes an independent chapter for innovation. In the annual report for 2015, Joy introduces its innovation achievements: "Our new P&H® Hybrid Excavator/Shovel offers shovel operators mobility and precision in the bank while lowering cost of ownership by 15%. Our proprietary Switched Reluctance (SR) Hybrid Drive technology significantly reduces fuel consumption and is featured in the hybrid excavator/shovel. It is also in our new Joy family of underground loaders, enabling faster acceleration and more tons moved for the hard rock market. We're also deploying our transformational DynaCut technology that mechanically cuts hard rock, eliminating the need for explosives".

When it comes to the general figure regarding sales and R&D, Joy Global is even more notable. Including revenues from maintenance and repair services, diagnostic analysis, fabrication, mining equipment and electric motor rebuilds, equipment erection services, training, and sales of replacement parts, service sales account for 74%, 69%, and 55% of Joy Global's consolidated net sales for the fiscal years 2015, 2014, and 2013 respectively. As a class of products, sales of original equipment for the mining industry accounted for 26%, 31%, and 45% of Joy Global's consolidated net sales for each of those years. The increased percentage of service sales is due to the deterioration of mining industry conditions during the period.

Fiscal year Nov - Oct.	2014	2013	2012	2011	2010	2009
Joy Global Net Sales or Revenues (US dollars)	3.78B	5.01B	5.66B	4.4B	3.52B	3.6B

Table 14: Revenue of Joy Global.

Joy Global is strongly committed to pursuing technological development through the engineering of new products and systems, the improvement and enhancement of licenced technology, and related acquisitions of technology. R&D expenses totalled US$40.6 million, US$49.0 million, and US$47.8 million for the fiscal years 2014, 2013 and 2012 respectively. These figures are striking for Joy Global invested 10.7%, 9.18%, and 8.45% of its revenue in R&D. What is more interesting is that, as total sales decreased, Joy Global allocated a larger proportion of money for R&D.

6.2.4 Sany

For the purpose of undertaking comparative studies, I visited one Chinese company's website. Two Chinese companies ranked top 10 in the construction equipment ranking; one is XCMG or Xugong (徐工), the other is Sany or Sanyi(三一). The second was chosen because it produces more mining equipment than construction equipment[60].

SANY Group is a global company in the construction machinery industry with a vast product range of concrete machinery, excavators, hoisting machinery, pile-driving machinery, road construction machinery, port machinery, and wind turbines. It is the sixth largest heavy equipment manufacturer in the world, and the first Chinese company in this industry to enter the FT Global 500 and the Forbes Global 2000.

Sany emphasises R&D. It constantly works in technology innovation. Its post-PhD working centre has become one of the country's top technical development centres. Through its expertise, Sany has also obtained over 3,600 authorised patents and hundreds of key technologies.

The General Research Institute of Sany Group, which leads over 30 research institutes, is the primary R&D department for technical research and technical management. The Institute owns eight sub-departments, including the Director's Office, the Research Management Department, the Technical Standardization Department, the Intellectual Property Right Department, the Product Data Management Department, the Experiment & Testing Centre, the Industrial Design Centre, and the Human Resources Department, and it is in charge of the management of the Post-Doctoral Research Station and the Academician and Expert Workstation. The Institute is also responsible for developing technology applicable to all Sany products, conducting forefront technical research on new products and setting standards, researching vibration, impact, noise, hydraulic technology, power matching and energy saving, new materials and control systems, creating innovative

60 It is difficult to find a mining equipment manufacturer ranking. Meanwhile, most mining equipment manufacturers also produce other machinery. The largest coal mining equipment manufacturer in China will be introduced in the sixth chapter as one case study.

technologies and conceptive products, and building up a network-based special and generalized platform for experiments and tests so as to share general experiment and test results. Each year, Sany invests 5%-7% of sales revenue into R&D. This figure matches those for Caterpillar, Joy Global, and Komatsu.

6.3 Conclusion

From the above summaries, some innovation patterns for mining companies and equipment manufacturing companies may be discerned. Mining companies mainly engage in process innovation, defined by OECD as: "A new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software"[61]. This kind of innovation entails less investment and results in either a lower cost or a higher output rather than a new product. The dynamics of undertaking process innovation in the mining industry are often endogenous, as this might be the most effective way for a mining company to enhance its profits. After all, the quality gap between different mining companies is not wide enough to make a specific company stand out. Mining companies seldom create something which does not exist but extract something which has been buried under the earth's surface for a long time, therefore valuable mines are almost all the same. Meanwhile, many other industries' innovation dynamics emerge from fierce product competition. Mining equipment companies are a case in point. Reducing production costs is also a way to make profits, but their customers' increasing requirement for the quality of the equipment puts more pressure on these equipment manufacturers. Product innovation is defined by the OECD as "A good or service that is new or significantly improved". Meanwhile, "This includes significant improvements in technical specifications, components and materials, software in the product, user friendliness or other functional characteristics"[62] play an important

61 http://www.oecd.org/site/innovationstrategy/defininginnovation.htm viewed on 2017-1-21.

62 Ibid, viewed on 2017-1-21.

role.

Mining companies tend to have close relationships with academic institutions, while equipment companies tend to rely more upon their in-house R&D sectors. While, western companies tend to rely more upon their in-house R&D than their Chinese counterparts, Chinese companies have more intensive interactions with academic institutions. This is because Chinese policies encourage this type of technological co-operation. In the previous chapter, I argue that Chinese mining equipment companies lag far behind their international counterparts. This is due to the fact that they neither build close relationships with relevant academic community nor do they have strong in-house R&D capabilities. While for Chinese mining companies, their academic partners' technological assistance has narrowed the gap with western mining giants.

If viewed through the optic of the Triple Helix, this phenomenon can be explained thus. The mining equipment manufacturers have internalised the 'university' helix, which means they can produce useful knowledge within their own companies, and at the same time they have rendered governments' direct participation in their innovation process unnecessary. It is helpful to return to the two kinds of Triple Helix which were discussed in the previous section, namely, the institutional Triple Helix and the functional Triple Helix. The institutional Triple Helix takes into account the features of the mining companies' innovation process, while the functional Triple Helix better reflects the equipment manufacturers' innovation process. Mining equipment firms in developed countries count on their in-house R&D to perform novelty production functions, while the highly developed rule of law system and the company' s administrative hierarchy perform the public control function. As a result, the functional Triple Helix still works here although nowhere could one find the institutional Triple Helix in this case. For mining companies, on the other hand, the first Triple Helix model, namely, the institutional or explicit model, is often found, especially in Chinese mining companies. That is to say, in this field the division between functions is still a dominating factor.

How have the two kinds of Triple Helix models been formed? Von Hippel's work offers one possible theoretical explanation for the two Triple Helix models in mining and equipment manufacturing respectively. He discusses the relationship between the stickiness of information and the locus of problem-solving. In his 1994 article he defines the stickiness of a given unit of information in a given instance as: "the incremental expenditure required to transfer that unit of information to a specified locus in a form usable by a given information seeker" (Ibid, p. 430). The technical problems a mining company needs to solve do not require the company to internalise all the relevant resources as they tend to be less sticky. These problems can be solved by inviting academic staff from an institute or a university. The problems include the design of a new mining method, improvement of a processing method or mineral dressing chemicals, while the academic staff can go to the site several times to familiarise themselves with the situation and conduct research in their own organisation by utilising their own facilities. This can help the mining company minimise the cost and maximise the benefits. In China, the cost of this process can be further reduced by the communication channel established in history, that is, the policy which encourages co-operation between mining companies and academic organisations. When it comes to the equipment companies (not only mining equipment companies), their technical problems are more complicated and the information needed to solve them is stickier. Therefore, the fewer the locus of problem-solving, the better. The best way is to use inside resources, which means an in-house R&D department. The Triple Helix in this field actually becomes an intra-firm Triple Helix. The product innovation has higher requirements of capital and the relevant facilities are often more expensive. Moreover, these facilities are more generic as they can be used in different situations. In mining companies, once and for all solutions are rare. Companies need to cope with a variety of situations. If they prepare equipment for all these situations the cost would be unbearable, thus it is more economic for them to seek external partners.

From the above three chapters, the factors that determine the success and failure of innovation in Chinese mining industry have been displayed. The ensuing chapter will discuss the policies which might have contributed to some of the undesirable innovation results.

7. Policy Implications

Based on the systemic analysis of the Chinese mining industry, this thesis also seeks to suggest some policy implications, although these implications will not only focus upon mining, but try to cover a larger industrial system. To begin with, the ideal perfect market does not exist and will not be innovation-friendly. As a result, it is useless to argue whether the government should play a role in a System of Innovation or Ecosystem of Innovation. A question worth pondering is how the government could play its role well in a (eco)System of Innovation.

I firmly believe that a strong industry system is one of the critical requirements of a healthy economy and innovation is to this healthy and sustained economy what fuel is to an engine. Policy could and should plays a catalytic role to encourage innovation. In this chapter, some stylised facts will be presented, then a theoretical analysis of these facts will be provided. Finally, a few policy implications will be proposed. These facts and theories will be closely linked to the former chapters of the thesis though not confined to them. The case studies and theoretical framework introduced in this thesis will be used to illustrate some arguments. The situation in Chinese mining as well as some other industries will be looked at.

7.1 Some stylised facts about Chinese innovation.

7.1.1 Insufficient investment in basic research by enterprises

It is common knowledge that the proportion of R&D investment over GDP has improved recently. Governments have designed various policies to encourage R&D investment, and if evaluated from the aggregate figure, these policies have yielded good results. However, complaints about the weak innovation ability of Chinese firms are still not rare. Of course, a number of years might be needed if the increase in R&D investment is to be transferred into an enhancement of technological capability, but this aforementioned contradiction can also be partly explained by breaking down the general R&D investment into different categories and comparing the change in quantity and proportion between each category or comparing it with the corresponding figures in developed countries.

According to international routines, R&D investment is usually divided into three parts, namely, basic research applied research and experimental development. The most authoritative definition of these three kinds of R&D activities is given by Frascati Manual (2002, p77-79):

> Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.
>
> Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.
>
> Experimental development is systematic work, drawing on knowledge gained from research and practical experience, that is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed.

After breaking different countries' R&D investment down into these three categories, it can be found that, recently, most of the increased Chinese R&D investment belongs to the third category, experimental development. In terms of proportion, the first category, basic research, even suffered declining investment. In developed countries such as America, Germany, and Japan, the contrary happened, that is, the proportion of basic research in total R&D investment has increased, and this figure in those countries is several times higher than that of China.

More specifically, in the American R&D system, the federal government, enterprises, and some non-profit organisations increased their investment in basic research, which kept the proportion of American basic research investment between 13% to 20% in the past half century. The ratio between basic research, applied research, and experimental development remained 1:1.4:3.9 between 1981 and 2009. The figure for 2009 was 1:1:3 (Liu et al, 2014, p83). The relatively stable ratios and proportions reflected American characteristics and the demand for the three kinds of R&D in a mature System of Innovation. If we look at who are sponsoring basic research, it can be found that American universities are the most important sponsors. Approximately half of the basic research investment in America came from universities. The concrete figures were as follows. In 1979 the figure was 48.9%, in 1989 46.7%, and after the Cold War, this figure slowly increased to 54% in 1999, 57% in 2004, and 53.4 in 2009. This is partly due to the end of an era of military confrontation leading to a decline in government funding in basic research (Ibid, p85). Meanwhile, American industry investment in basic research also increased. In 1979 American firms contributed 13.5% of the total American basic research, while in 2009 this figure had been raised to 19.5%. During that period, there were some fluctuations but the general trend was that American firms invested more in basic research (Ibid, p.85). Compared with universities and firms, federal laboratories and R&D centres cut their basic research investment after the end of the Cold War. In 1979, they accounted for 28.9% of the total basic research investment and this percentage then decreased slowly. In 2009 this figure was 14.9% (Ibid). A further breakdown of American firms' R&D investment will make things clearer. During the period 1981 to 1990, American firms' average annual R&D investment on basic research was about 3.45%. During the 2000s this figure was 4.02% (Ibid, p.88). It is obvious that both the basic research among the three R&D investment categories and the investment of basic research by firms has ascended over the past 20 years. During the same period, American firms invested less in applied development. This figure used to be a bit over 20% but in

2009 it fell to a bit less (Ibid). As for American firms' investment in experimental development, it has risen from 75% to 80% (Ibid). To sum up, the two ends of R&D, namely, basic research and experimental development, have received more funding, while the middle part of this chain, i.e. applied research, received less and less funding in terms of proportion of total R&D. By and large, that a firm invests more in experimental development is not strange as this stage is close to the final commercialisation stage, whereas the increase in basic research investment by a firm is interesting since basic research is further away from commercialisation. We can shed some light on this by analysing the content of firm-conducted basic research and its relationship with a firm's revenue. This will be analysed later. American firms' increasing investment in basic research is to some extent a guarantee of their technological edge in this information epoch. A number of American innovations can be attributed to American firms' strong basic research ability as they apply entirely new technology rather than improving already existing technology, firms without strong enough basic research ability cannot conduct this kind of innovation.

Germany demonstrates similar trends. Germany industry boasts of its tradition of attaching importance to basic research; no wonder the research university and the in-house R&D agency were invented by the Germans. One of the key characteristics of German science and technology policy is that it keeps its basic research at a high level in order to remain at the cutting edge. Basic research usually occupies about 20% of total German R&D investment. As for German firms, their investment in basic research has also risen. In 2001 German firms' investment in basic research took up 4.7% of total R&D investment, this figure rose to 4.96% in 2007, and further increased to 5.42% in 2009. As for the other two parts of R&D, the investment in applied research suffered a slight decline in terms of its total proportion of total R&D investment, dropping from 51% in 2001 to 48.4% in 2009. Regarding experimental development, it increased to 46.2% in 2009 from 44.3% in 2001 (Ibid, p.91). The three categories of R&D investment display the same trend as their American counterparts, that is, the two ends increased while the middle sank.

Japan's situation is almost the same as Germany's and America's. From the perspective of Japan's R&D investment, in the industry community the ration remained stable at 1:3:12 (basic research: applied research: experimental development), while the whole country's R&D investment structure remained at 1:2:4. As for Japanese firms, their investment in basic research suffered a slight downturn in the 1990s (rainy days for the Japanese economy), then returned to its 1980s level in the early 2ist century and remained stable at 6.5%. Again, Japanese firms' investment in applied research decreased and their investment in experimental development increased (Ibid, p92-93).

The Chinese situation, however, is quite different. Increased investment in R&D mainly occurs in the experimental development category. In terms of absolute quantity, all three categories enjoyed dramatic increase after 2006. But if measured in relative proportion, only investment in experimental development increased, while both of the other two categories suffered a decline in investment, especially applied research. The ratio between these three categories' investment was 5.2:26.4:68.4 in 1995, while the corresponding figure was 4.6:12.7:82.8 in 2010[63] (Ibid, p110). As for Chinese firms' R&D structure, investment in basic research can even be ignored compared with investment in experimental development. The former first slightly increased from 0.74% of total R&D in 1998 to 1.2% in 2004, which was also the peak year, then plummeted to 0.1% in 2010. The latter rose from 88.77% in 1998 to nearly 98% in 2010 (ibid, p.120). Chinese firms' investment in R&D increased during these years, the proportion it occupied doubled, but a great majority of this investment was poured into development s. According to China Statistical Yearbook on Science

63 In between 1995 and 2010 there were fluctuations but the general trend is that more importance was given to development than research.

and Technology, in 2010 the average number of R&D staff in charge of basic research in each Chinese firm has was 0.12, which means most Chinese firms did not engage in basic research at all (Ibid, p122).

In summary, despite the increase in R&D investment, Chinese firms still pay little attention to basic research.

7.1.2 Universities and Research institutes' overengagement in patent application

Universities and research institutes all over the world do apply for patents, some universities are quite good at this, but in most developed countries, firms are the main applicant of patents. In 2006, universities and research institutes put together accounted for 4.28% of all patent applications (universities accounted for 2.61% while research institutes accounted for 1.67% respectively), six years later the two put together accounted for 8.8% of all patent applications (universities accounted for 5.69% while research institutes accounted for 3.11% respectively (Zhang,2015, p86). The general trend is an upturn one, which reflects that knowledge production agencies are increasingly shouldering knowledge application functions, just as the mode-2 knowledge production model describes.

The date from China expose a different patent application structure compared with the developed countries. The contribution of Chinese universities and research institutes make to domestic patent application is far greater than their western counterparts. In China, the number of patents produced by universities and research institutes equals 40% of that of firms. In developed countries, only in France and America do universities make a significant contribution to domestic patent application, the number of patents produced by universities and research institutes in those two countries equals roughly ten percent of that of firms. Besides, if we break down the different category of patents into invention, utility model and industrial design, the result is that from 1994-2013, universities produced 49.97% of all the inventions, research institutes accounted for 45.77, the remaining 11.62% belonged to firms, which means Chinese firms mainly specialise in industrial design and utility model patent (Ibid, p60). The question is that it is the invention patent that represent one's real technological capability.

There are also divergences among different sectors. Universities and research institutes are relative active in the following sectors' patent application: bio-technology, pharmaceutical technology, materials, medicine, and nanotechnology. But even in these sectors, universities in developed countries applied less than 10% of the whole patents. In China, however, universities and research institutes have much stronger patent application ability. In pharmaceutical industry, the ratio between the number of patents produced by Chinese universities, research institutes and the number of patents produced by firms is 83.93%, in environment technology this ratio is 90.87%, bio-technology,229.1%, nanotechnology, the highest ,371.77%(Ibid, p92).

Apart from that, the quality of the patents produced by Chinese universities and research institutes have also got the praise of the largest patent operation company, Intellectual Ventures[64]. It has established close co-operation with dozens of Chinese universities.

Then, how to explain the two seems peculiar phenomena? This is the task of the next

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[64] Intellectual Ventures is a private company that centres on the development and licensing of intellectual property. Its business model has a focus on buying patents and aggregating them into a large patent portfolio and licensing these patents to third parties. Please see http://www.intellectualventures.com/

section. Some theoretical framework include the Triple Helix and System of Innovation will be used, the influence of some policies will also be analysed. The case study about mining industry will be used as factual argument to support this analysis as it is one of the most regulated industries.

7.2 Theoretical and policy analysis

The two Phenomena depicted in the previous section have something to do with many factors, but the most important reason might be the false faith in the innovation linear model.

This model has been mentioned once in this thesis, it sticks to the doctrine that basic research comes first, as the outcome of basic research represents the knowledge frontier of mankind, these outcomes are usually some ground-breaking theory or some new to the universe understanding towards some natural phenomena. Basic research helps people better interpret the world but has little connexion with changing the world, since at the very beginning, even the most gifted researchers cannot completely comprehensive these new understandings, let alone the technical staff and engineers. Then comes the applied research. As time goes by, more experiments and research will be conducted to improve people's understanding towards the new discoveries in basic research stage. With the accumulation of knowledge regarding the practical usage of the fruits of basic research, some research results which have potential commercialisation opportunities will be filtered out. The main task of this stage is not to understand the world better but to find useful tools to change the world, this task has to be based on the achievement of basic research, since without knowing the world better it will be impossible to change the world effectively. The former two stages' work are mainly undertaken by university scholars and the researchers in research institutes. The third stage of this innovation chain is development, some firms' in-house R&D began to take part in this stage as the outcome of development could be their products. The last stage is operation and production, the prime business of firms. According to the supporters of linear model, most innovations have to go through such a complete linear process, an innovation starts with a discovery in basic research and finally it is the firms that get the largest share of the profit. This chain has strict chronological requirement, the earlier stage must come predate the later stage.

Eloquent this theory sounds to be, it cannot be justified by a study of industrial or technological history. This thesis has mentioned Stokes's study, he first challenged the categorisation of research, he created a 2*2 matrix based on two dimensions, namely whether this research has practical concerns and whether it has understanding concern. If the linear model is correct, we should find that most innovations originated from Bohr quadrant (with only understanding concern, without practical concern, name after the Danish scientist Niels Bohr), in fact it is the research in Pasteur quadrant (with both practical concern and understanding concern, name after the French scientist Louis Pasteur) that produced most innovations. In history, we can also find loads of inventions that created a new scientific discipline, which is the reverse order of the linear model. This linear model was proposed by V Bush(Bush,1945), he was thinking about how to make the best use of the migrant scientists and keep America's leadership in science after the war. The Bush report did help American's basic research, which can be reflected by the rocketing investment of the federal government in basic research and the soaring number of American Nobel prize laureates. Unfortunately, American's innovation performance was far from desirable. The linear model's negative influence should be responsible for this. Of course, it is not to downplay basic research's significance here, the aim is to point out that increasing investment in basic research will not automatically lead to an improvement of innovation performance, innovation policies hope to encourage innovation by spurring scientists doing basic research to commercialise their discoveries is like climbing a tree in order to find fish, in a

Chinese proverb.

The linear model deeply influences policy makers' thinking pattern. Just because of this, the policy makers believe in linear model design and implement policies which cause the above mentioned strange phenomena. The logic of these policy makers is as follows, in Chinese System of Innovation, universities and research institutes are in charge of conducting basic research, as a consequence the funding for supporting basic research granted by government will be allocated to them. The industrial laboratories have close links with industry, they also have well-trained researchers, therefore they will undertake applied research. Firms are at the front line of production, they will be responsible for commercialising the outputs of applied research. As is clearly shown that each subject shoulders specific obligation, they are only expected to finish their own task. This logic is helpful in pursuing the cause of these phenomena. Innovation policies do not deem it necessary for a firm to do basic research, as it is considered as the universities' turf. In fact, a firm directly face the society and ought to be an ideal place to produce research fall into the Pasteur quadrant. If the ability of doing basic research of a firm was discouraged, when the firm encounter problems, it will be unable to solve the problem, especially when the problem-solving requires the ability to understand the reality. Under such circumstances, the firm has no choice but to turn to university or research institutes for help. This will only further marginalise the firm in the future problem-solving activity. In short term, this choice might be rational, but in the long run it will undermine the firm's technological capability, the additional and distinct resources needed to generate and manage technical change. A firm without this capability will be vulnerable during a transitional era, to make matters worse, if the whole countries firms are encouraged by this country's policy to give up basic research ability, it is the whole country that in danger. Meanwhile, policies tend to have a narrow sense of innovation in mind, innovation is the commercialisation of invention, which is true, but according to System of Innovation, innovation has multiple sources and is a collective outcome. Not only the production and operation stage is innovation, the whole process of innovation is very complicated, current policies only encourage firm to participate in the last stage of the innovation chain, thus isolate firms with other innovative activities, let alone this stage is based on the linear model. Firms are the subjects of innovation, innovation in a wider sense, they should be allowed or even pushed to take part in every part of innovation, otherwise firms could not become real subjects of innovation. Actively participate in innovation process and orchestrate innovation activities also entails a strong technological capability, then a mutual enhancing circle can be formed.

The second phenomena, i.e. the over engagement of universities and research institutes in patent application can also be explained by the policy practice of linear model. In this model, basic research is regarded as the origin of all innovation, an underlying logic is that if one wants to have more innovation, policy should focus on universities and research institutes, only when they keep producing useful basic research outcomes, could the downstream players take turns to do the remaining work. Consequently, numerous policies forcing academic institutes commercialise their outcome have been designed and implemented.

This linear model also influences some policies in relation to mining industry. One policy which has been mentioned is that mining companies and academic institutes have to co-operate with each other in order to get national funding. This policy assumes that academic institutes possess theoretical knowledge and they need to be put into practice, whereas mining companies understand the reality better but they lack theoretical guidance. This assumption locates academic institutes and firms at the two ends of the innovation chain, it does yield desirable result these years, but one lurking danger might also be caused by this policy, namely firms would not choose to strengthen their own technological capability when they have easy access to outside technological resources. Another policy is worthy to be discussed here, recently China is establishing some intermediary institutions, the logic is apparent, these institutions will conduct applied R&D task, downstream firms can contact these institutions when they are interested in some technologies, they will be playing at the middle of the innovation chain. Again, these intermediary institutions will be helpful in short term, but they are only transitional institution, policy makers should bear this idea in mind: policy's ultimate goal is to make a contribution to the fostering of a firm's own technological capability.

7.3 Discussions

The phenomena proposed in the first section of this chapter can be linked with some policies, in order to stop this distortion more proper policies are needed.

Above all, treating firms as the subjects of innovation cannot only be a propaganda slogan but has to penetrate into every innovation policy. This is not a useless repeat, the question is that a number of policies only claim they regard firms as the subject of innovation. Actually, they just perceive innovation in its narrow sense, and only pay attention to firms at the production and operation stage. This philosophy merely treats firms as a production unit rather than the core actor of innovation. More appropriate policy should encourage firms to engage in every part of innovation and build capacities which will be required by innovation. The policies trying to improve the interactions between firms and academic institutes could be remained only at the premise that firms' endogenous ability to innovate should be the prime concern of such policies. Besides, establishing funding for firms to do basic research, this funding could be independent from the funding for academic institutes. The intermediary institutions should also be paid attention in order to direct their impact to facilitate firms to build in-house R&D rather than impair firms' motivation to internalise the outside R&D institutions.

Secondly, the accuracy of innovation policies should be increased. Government cannot replace firms to do innovation but it can design policies to reward the firms doing indigenous innovation. There are no perfect measurements about innovation, the best way to identify such a firm is interviews and visiting in person. Government can use public procurement policies to support the firms doing indigenous innovation. Other firms which infringe indigenous innovation firms' intellectual property rights should be severely punished.

Last but not least, the strong patent production abilities of Chinese academic institutes should not be ignored. Government should help these institutes find Chinese partners to realise the potential commercial value of these patents. Academic staff should not be forbidden to take commercial work if they can fulfil their basic academic tasks. Firms should also be encouraged to seek high quality patents, government can build platforms to bring them together.

8 Conclusion

In contemporary China, even the rank-and-file care about how to improve China's science, technology and innovation performance. Solving this problem is imperative for the successful promotion of the Chinese economic structure. In order to narrow the reach of this research, mining is chosen as the research target. It is a strategic industry as it is indispensable for China's future energy security and some materials produced by the mining industry can be used and have no equivalents when it comes to manufacturing a constellation of high-tech products. In the foreseeable future, mining will not disappear in China. As long as the country maintains a GDP annual growth of around 7%, the products of the mining industry will be necessary for its development. It is also timely research as at the very beginning of this research, the mining industry was in its heyday while as the research ended, this industry, not only in China but across the world had seen a slump. This is not lucky for people working in the mining industry but it is fortunate for me as an outside observer to see what kind of decisions each Chinese mining company and mining equipment manufacturing company made, and to witness the responses of the Chinese government. These actions are essential in determining the vision of Chinese mining and the case studies presented here map a panorama of this transition period.

The mining industry is also a hard case for an innovation study, as it is often regarded as a sunset and labour-intensive industry, but if only one industry can be studied the hardest should be more persuasive. By and large, mining is not considered as a high-tech industry as most examples belong to manufacturing. Mining itself is all about digging up something which has already existed for tens of millions of years, rather than creating something that does not exist. Compared with manufacturing, mining mainly focuses upon the innovation process, which locates it at the middle part of the industry chain. Both the early part of the industry chain, namely, mining equipment manufacturing and the late part of the industry chain, namely, metallurgy or material manufacturing, have a better image as regards innovation. As a result, this research does not seek to prove that there is more innovation in the mining industry but to demonstrate how the mining industry has improved not only its own innovation performance but its upstream and downstream industry simultaneously. The mining industry per se might not be an innovative industry according to the standard definition of high-tech industry (the percentage of R&D investment in total revenue), but it can, and in some cases does, help the industries linked to it enhance their technological capabilities.

As far as development studies is concerned, innovation is a useful and powerful tool for a country's development, but it is only a means not an end. Consequently, the relationship between innovation performance and economic development has huge significance. Mining is an ideal industry for conducting such research, especially in China. The reason is obvious. In China mining is not only an industry following pure commercial logic, but can be viewed as an extension of the Chinese state. Most of the largest mining companies and equipment companies are state-owned, so the development of the mining industry is a typical political economy phenomenon. After the term 'indigenous innovation' became popular, mining had been influenced intensively by relevant policy. Numerous policies implemented by the Chinese government, such as the environmental protection policy, the domestication policy, the R&D encouragement policy, have to some extent altered the course of the mining industry. Most of the mining SOEs have no choice but to follow government instructions. This research also looks at the impact of the innovation policy or science policy on mining companies as this also reflects the state's capacity.

There are a number of ways to approach innovation. This research adopts a qualitative method. I believe that the quantitative method is appropriate to identify a correlation between different factors. Whereas the aim of this research is to find the mechanism through which innovation outcomes can be determined, the qualitative method is beneficial in presenting such a mechanism clearly.

More specifically, this research is first illuminated by the System of Innovation(SI) theory. SI views innovation as the outcome of a system of innovation. It is contended that this framework is very useful for development scholars other than for innovation scholars. The System of Innovation theory is not a visible system with a certain boundary. On the contrary, it is based on the perception of a researcher, thereby leaving space for individual interpretation. Development scholars can choose some 'components of the System of Innovation' which they regard as significant for both innovation and development to construct a personalised 'System of Innovation'. In other words, this is a flexible framework which is inclined to change and evolution. This framework is especially apt for this research as, although the theme of the research is innovation, it only regards innovation as an indispensable tool for China's development. By incorporating many multi-functional components (such components play a role not only in creating or diffusing innovation but also in other fields) into the System of Innovation, the significance of this research will not be confined to innovation alone. The System of Innovation is a perfect tool to combine the study of innovation with that of the economic development of a country or a region.

The System of Innovation is quite useful in providing insights, but it is not a very practical framework as it is a rather grand theory. This research adopts the Triple Helix (TH) approach to organise interviews and conduct fieldwork. The two frameworks have different focus points. The SI approach attaches more importance to firms, whereas the TH approach emphasises the role of universities in knowledge-production. As innovation can be viewed as knowledge-production activity, the TH approach can also be used to study innovation. In theory, the SI approach incorporates more potential innovation contributors but in practice the TH approach offers more feasible guidance to researchers due to its more concentrated focus.

These two approaches do not contrast with each other; they are just different lenses for researchers. The TH approach focuses upon the interaction of universities, governments, and industries. These three core players are also the most significant contributors to a System of Innovation. The case studies here are also conducted according to the Triple Helix approach. The main targets of the case studies are different, some focus upon one company, some focus upon a regional industry. Regardless of these differences, I attempt to demonstrate whether there are Triple Helix interactions in play in these cases, if so how does this interaction contribute to any innovation output, and if not, why.

A newly proposed theoretical Innovation Ecosystem is also used throughout the research. It was designed with the aim of bringing more dynamics to a relatively stable System of Innovation framework. It also scrutinises the functions rather than the institutions of a system, shedding new light when combined with the Triple Helix approach.

These three theoretical frameworks inform all the case studies. Case studies are used to demonstrate the details of real innovation processes. To give all the case studies enough structure, the three theories were used to organise the writing up. Even the cross-country comparison study was analysed through the lens of the Triple Helix and the System of Innovation. The results of this coherent analysis will be presented below. To sum up, the empirical study component of this research consist of case studies with a theoretical analysis using the System of Innovation, the Triple Helix, and the Innovation Ecosystem.

Based on the foregoing, this study looks at innovation in the Chinese mining industry through a systemic approach and attempts to answer the question: What factors determine the success and failure of innovation in Chinese mining? It is expected that these factors are also useful in explaining the innovation performance of other industries in China, as these constitute elements of a National System of Innovation.

This research owes its academic originality mainly to the National System of Innovation, and whilst it is not intended to be a study of the Chinese National System of Innovation, it is to some extent a study of the Sectoral System of Innovation in the Chinese mining industry. The purpose of this research is to find an entry point into China's System of Innovation. A more ambitious goal is to identify the weak point of the system and make a contribution to its improvement.

The research yields two main conclusions, one empirical, the other theoretical.

The most important empirical finding of the research is that divergence of innovation performance across the different part of the mining industry chain has been identified. More specifically, compared with the prospecting and manufacturing stages, the mining and mineral processing stages are more innovative. I would argue that the divergence of innovation performance across the different stages of mining is caused by two factors. First, the distance between its final products and market or commercialisation and second, the intensity of the interaction between the mining company (including the prospecting company and the equipment manufacturer) and the university or research institute. To be more specific, the closer the distance and the higher the intensity of the interaction, the better the innovation performance. One can find numerous laws in China which encourage the co-operation of mines with universities and academic institutes. This is a vivid positive example of the Triple Helix; all three parts are actively engaged in this interaction. By contrast, as firms specialising in machinery manufacturing do not co-operate intensively with other components of the innovation system with which they are involved, this leads to relatively poor innovation performance. Moreover, in China policies create a man-made gap between prospecting per se and its potential commercial contribution. As the innovators and the practitioners at the prospecting stage are neither the same group of people nor have they collaborated as they do at the mining stage, this separation obstructs interaction between the innovators and the customers, which is vital for innovation in a knowledge economy. The policies regulating prospecting also make no contribution to bringing universities and industries together. In fact, policy-makers are very reluctant to create a prospecting industry in China. The status quo is by no means formed in an institutional vacuum, history matters. The current situation is a natural extension of that in the past. Intensive interaction between mines, universities, and research institutes was established in the pre-reform era, policy-makers stipulating that universities focus upon basic research, research institutes focus upon applied research directly linked with production, while mines co-operated with academic institutes. Whilst for prospecting and machinery manufacturing, companies were not encouraged to communicate with their downstream or upstream customers, they mainly talked to superior authorities. Consequently, nowhere can one find a positive Triple Helix in the two areas. A positive in this explanation is that history can shape something, history can also change something. The status quo can be changed for a brighter future and this change is occurring.

One possible theoretical contribution of this research is that the Triple Helix appears in different forms under different circumstances. The development stage of a country, the various growth stages of a firm, the different feature of an industry, all have impacts on the shape of a specific Triple Helix. In order to grasp the core of a real innovation process, I propose a dichotomy of Triple Helix, institutional Triple Helix, and functional Triple Helix. The functions of university, industry, and government in the Triple Helix are novelty production, wealth generation and public control respectively. The former can be regarded as three kinds of institutions, therefore we can dub the university-industry-government Triple Helix as an institutional type. The question is that, in reality, in some successful innovation stories one or even two helices might be missing. For instance, universities have little direct impact on equipment manufacturing. Under such circumstances, the functional Triple Helix works. This Triple Helix focuses upon the three functions of novelty production, wealth generation, and public control. As long as these functions can be performed, a complete Triple Helix interaction can be finished. The case studies in this research demonstrate that the second Triple Helix grasps the essence of this model, as in some cases, one cannot discern the direct impact of government or universities on innovation. Only firms can be accounted for. This discovery, however, will not make the Triple Helix framework obsolete. When an institutional Triple Helix does not exist, a functional Triple Helix comes into play. One strong helix might be able to absorb or internalise another helix's or even the other two helices' function, hence the other two helices as visible institutions disappear but their functions will not disappear. In this research, firms are always seen the strong helix, as this research is about innovation and firms are the subject of innovation. But there are some situations in which it is difficult to distinguish different helices, especially in the Chinese context. This has something to do with the context in which the Triple Helix was constructed. This framework is constructed within Western context, even in the western world it is cannot be expanded to study all countries.From early on, American Universities shoulder a number of responsibilities of bolstering local development, as a result the University helix in America is not a pure academic helix. For Germany, the birthplace of research universities, this kind of mutual task accomplishing between universities and firms might be a phenomenon worth contemplating. When it comes to China, the system of innovation,especially the higher education system of China is increasingly resemble that of America, with the extant policy which encourage the interaction of universities and firms the Triple Helix interactions are becoming more and more significant in China. But TH still face a problem the boundaries of the three helices are not as clear-cut as those in the west. Two examples can be offered here. First, the Founder Group, a Peking University-run company. Is it fair to say in the Founder Group's case it is the university that absorbs the firm's functions? Second, the Chinese Academy of Science (CAS). This is a research institute that runs a lot of companies. Moreover, it is a public institution thus it can be regarded as branch of the Chinese state. Is it fair to say in this case that the three helices merge with each other? Under different circumstances, the importance of the three helices is prone to change. This situation remind the scholars that when use TH, history and context matters.The TH should be regarded as a dynamic description about the situation in a country or during a specific period of time, it is a framework which is conducive to condense the complicate data, it is by no means a perfect benchmark for all the countries. It sometimes can be deemed as a philosophical tool for researchers to push forward their work, but whenever use it in whichever context, its flaws should not be ignored, the situation it depicts should not be taken for granted or be set as a model for others to mimic. This research finds that it is not always useful in explaining the innovation stories in China,especially the institutional TH, as the institutional setting in China is quite different from the west.The functional TH,however, is more useful as it focus on the abstract functions instead of the concrete institutions. By proposing such a new form of TH model, this research can expand the application field of Triple Helix.

In fact, as Etzkowitz and Leydesdorff point out, the obvious trend is that the three helices shoulder tasks which used to be the domain of others. Is this a good thing or a bad thing? Can we find laws or rules for this kind of mutual penetration? This preliminary finding also paves the way for future research in this academic vein, asking, for example, is there an optimum form of Triple Helix, what features determine the form of a Triple Helix, can one achieve better innovation performance by actively changing the Triple Helix interaction of an industry or a country, does the evolution of a Triple Helix demonstrate similar patterns in the industry/country this Triple Helix pertains to, and how do we evaluate the difference?

Actually, China has achieved a great many improvements in innovation in a wide variety of fields. Taking mining as an example, if one wants to learn some mining methods such as top coal caving, China is definitely the first choice. Although the reason why China is the best teacher of some mining methods is that, due to the geological requirement of these mining methods, not every country can use them, the advancement and effort Chinese technicians have made are still significant. This situation partially proves that the current System of Innovation in China is efficient in some ways, although it is far from perfect. Most innovations are linked with practical needs, at least at the mining stage. the Chinese System of Innovation has been effective in transferring these needs into technical language and finally commercialising the technological breakthroughs. This research provides some explanation of the admirable innovation performance of some parts of the mining industry. It also offers a brief analysis of Huawei's case. Huawei adopted R&D to make itself excel over its competitors while meeting the market demand, while mining companies in China tend to establish technological relationships with universities and research institutes. Taking the constraining political and geological factors into consideration, it is not fair to regard the mining industry as an innovation failure. China still lags behind the West in many scientific and technological areas but it is also catching up in a lot of fields. The future of Chinese innovation is still uncertain, whereas to say it is prospective is not groundless.

China has entered a so-called 'new norm'. During this period, economic growth has slowed and the annual GDP growth rate is about 7%, which is high compared with other countries but rather low compared with China in the past 30 years. In fact, there was no old norm. After the Reform and Opening-up, China's economy suffered several rounds of fluctuation, each wave lasting for roughly 10 years, and the downturn as well as the upturn can be explained by the implementation of new policies. In some years the GDP growth rate was even lower than it is now. The difference between this era's economic 'recession' and the earlier experience is that China's current economic structure is increasingly similar to that of developed countries, and innovation has played an important role. Actually, an ideal new norm should be one in which technological innovation becomes ordinary, will be the norm for most firms, and the quality of GDP will improve due to the significance of innovation.

Mining's role in China's economic growth is also going through a transition. The astonishing economic growth of the past three decades would have been impossible without a high level of coal use. In 2015 the share of coal in the energy mix fell to 64.4%, which has characterised a fundamental shift in the Chinese economy's relationship with coal, one that has gone largely unnoticed until the recent peak in consumption (Qi et al,2016, p564). The extensive use of metals is also becoming impossible both economically and politically. The notorious pollution around Beijing has led the government to impose strict regulations on firms. A more environment-friendly economy is in formation. During this transition period, technological innovation will be critical to its success. Those so-called 'high-tech' industries only take up a minority share of industrial output. Only by realising the diffusion of state-of-the-art technology throughout the whole economy could the economy be promoted, and as a material provision industry for all other industries, mining is qualified to be a testbed and lay the foundation for the Chinese economy. Actually, it is common practice to adopt information and automation technology in mines all over the world, some mines operated by global mining companies are quite technology intensive.

The coming decades are essential for China's development, the same goes for the Chinese mining industry. The latest statistical data suggest that in 2016 the mining industry's profits amounted to 182.5 billion yuan (US$27 billion), a 27.5% decrease, while profits from coal mining enjoyed a 220% increase, non-ferrous metal metallurgy's profit also increasing by 42.9%[65]. These figures show that mining will continue to be an important industry, but it is likely to weather fluctuations and intra-industry divergence. The fate of mining cannot be separated from the development of China. Successful late developers will serve as guideposts for successors so their experiences are precious. The impact of China's development, be it a success or a failure, will be huge for the rest of the developing world. Its way of

65 http://www.gov.cn/xinwen/2017-01/26/content_5163619.htm viewed on 2017-2-17.

dealing with innovation will determine the trajectory of this development, which will keep to be an attractive myth for generations of scholars and practitioners.

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