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POLICIES, RESEARCH, INNOVATION, AND PRODUCTIVITY: AN ANALYSIS OF THE CHINESE AGRICULTURAL MACHINERY INDUSTRY

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ABSTRACT OF THE THESIS

Policies, Research, Innovation, and Productivity: An Analysis of the Chinese Agricultural Machinery Industry

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This thesis examines the role of R&D and innovation plays in productivity based on the agricultural machinery firm data from the annual report of National Bureau of Statistics. A structural model (the CDM model) which describes the linkage between R&D investment, innovation output, and productivity is applied. The empirical results suggest that there is a significant positive correlation between R&D investment and innovation outputs, as well as R&D investment and productivity. However, the association between innovation outputs and productivity is for this set of observations not yet established as significantly positive.

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SECTION 1 INTRODUCTION

The world witnessed the miraculous growth of China’s economy in the past three decades. Unprecedented reform and development in agriculture have helped China achieve grain self-sufficiency and get rid of hunger and poverty. China is now in a vital stage of accelerating industrialization, urbanization and agricultural modernization. It leads to higher requirements in agricultural productivity.

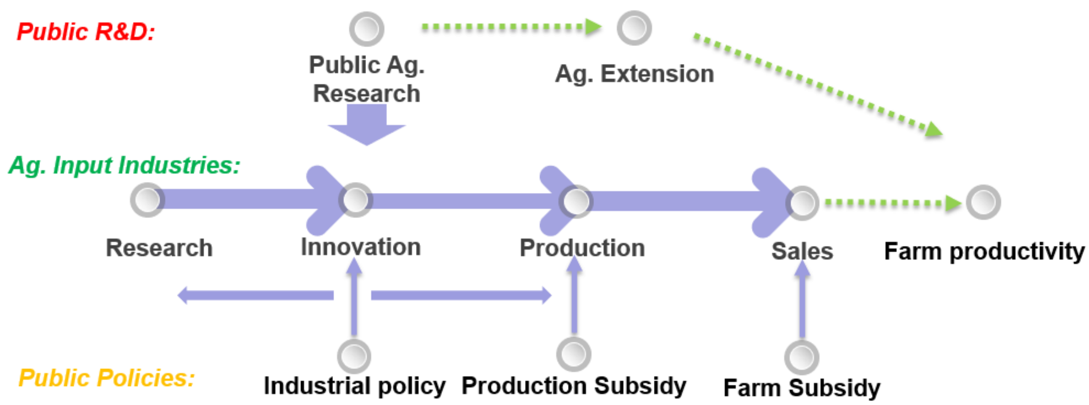
As an indispensable tool in modern agriculture, agricultural machinery plays an important role in increasing agricultural productivity, boosting farmer household income, promoting rural development, and safeguarding national food security. The Chinese agricultural machinery industry is growing rapidly. There is more than 20% increase for each value of total production value, sales, import, and export for several years and ranked among the top of the world regarding total volume now (Department of Equipment Manufacturing Industry, 2016). In 2015, the production of tractors, combining harvesters, plant protection machinery, and agricultural water pumps, ranked first in the world (Department of Equipment Manufacturing Industry, 2016).

There is still much room for the agricultural machinery industry to improve and upgrade. The growth in the past 20 years was mainly attributed to allocative efficiency improvement that originated from the Household Responsibility System as well as

Opening up and Market Reforms. Further industrial growth will depend on its capability to innovate and adopt new technology in machinery and develop and market new technologies that farmers need. Local Chinese companies, however, face great challenges in competing with the world leading companies from the U.S. Europe and Japan in open, global and domestic markets.

The “Made in China 2025” and the “Belt and Road” policies provide extraordinary policy environments and opportunities for manufacturing industries in China to transform and evolve. According to the guideline of “Made in China 2025”, by 2020, the Agri-machinery industry is expected to have a breakthrough in advanced technologies, green manufacturing, and energy saving (State Council of PRC, 2015). It will provide up to 90% in the domestic market, especially, the high-end machinery such as large-scale tractors and cotton pickers is expected to reach 30%. By 2025, the market share of domestically made agro-machineries is expected to be higher than 95%, and the high-end machinery will reach 60% (State Council of PRC, 2015). It will supply up to 90% of the domestic market, and in high-end machinery markets such as large-scale tractors and cotton pickers, it will reach 30%. By 2025, the market share of domestically made agro-machineries is expected to be higher than 95%, and the high-end machinery will reach 60%.

Figure 1 *Diagram of this thesis*



To fulfill the above goals and improve agricultural productivity, the Chinese government has set up various technology policies, fiscal policies and taxation support for the agricultural sector as well as the agriculture input industries. Therefore, the general goal is assessing policies by unpacking impacts through input industries to agricultural productivity. Due to the data limitation, the agriculture extension, and farm productivity, however, will not be included in this thesis. This main objective can be further broken down into the following specific components:

(1) Analyzing the linkage of R&D investment, innovation and firm's productivity

(2) Estimating the effect of public policies and public R&D on private R&D, innovation and firm's productivity

To fulfill these objectives, this thesis is divided into seven sections. Following this introduction part is Section 2, which outlines the historical and present background of agricultural machinery industry. After this, Section 3 presents a literature review to find out potential effects of public policies and the theoretical mechanisms of the linkage of R&D investment, innovation, and firm productivity. Section 4 presents data resources, describes dependent variables, and lists the potential determinants. Section 5 introduces augmented structural innovation framework with corresponding econometric methods which organize the methodology of this research. The descriptive analysis and estimated results with further discussion from the empirical analysis are presented in Section 6. Every fraction in the converting channel of R&D activities to firm performance will be scrutinized. Finally, Section 7 summarizes the research findings and conclusions, then offers further policy advice.

Results reveal that there is a significant positive correlation between R&D and innovation, as well as R&D and productivity. The association between innovation and productivity is, however, insignificant. Public policies have diverse effects. The production subsidy to firms has consistently positive influences on private R&D to firm productivity. Public R&D plays a "complementary" role to private R&D and innovation but affects firms' productivity reversely. The purchase subsidies to farmers encourage innovation and firm productivity by creating and expanding higher demand for agricultural machinery. From the aspect of firms' attributes, they are also key determinants. The firm size has an inverted U-shaped relationship with private R&D, innovation, and firm productivity. The firm's ownership and sources of investment will also matter R&D, innovation and total factor productivity (TFP). What is more, intangible assets have positive effects on R&D investment and innovation, while fixed assets have positive effects on TFP.

This paper makes some contributions to the literature. First, given the transitioning economy background, CDM innovation framework is used to analyze the entire innovation process, and to estimate driven determines of it. Second, causal effects of R&D activities and innovation return on firm productivity will be identified for the agricultural machinery industry. Third, different policies indictors in multi-dimension are combined into whether industry gains derived from the policy support.

SECTION 2 BACKGROUND

This section presents background information on the agricultural machinery industry in China and provides an overview of further studies. I first discussed the past agricultural mechanization of China in Section 2.1. The present performance of the agro-machinery industry is further presented in Section 2.2. Section 2.3 lists the related public policies of supply-side and demand-side. Section 2.4 presents the unique innovation system of the agro-machinery industry from public and private aspects in China. Finally, I summarize the general role of public and private sector in agricultural innovation in Section 2.5.

2.1 Agricultural Mechanization in China

In the past 40 years, the agricultural mechanization has achieved significant and brilliant improvement. Comprehensive mechanization rate reached 61% in 2014 from 30.5% at the beginning of the 21st century (Department of Farm Mechanization (MOA), 2014). By reviewing the past agriculture mechanization, we can draw lessons from the past and shed lights on future development. The course of agricultural mechanization can generally be divided into the following four stages: (1) Before Reform and "Opening up" (1949-1978), (2) Adjusting and Stagnating, (3) Transforming and Self-developing, and (4) Supporting and Orderly Developing (Liu, Yu, & Sun, 2008).

2.1.1 Stage 1. Before Reform and "Opening up" (1949-1978)

Before "Reform and Opening-up" policy, which was announced in 1978, China was under the constraint of the planned economy system. The government controlled economy which led to the inefficient allocation of capital and resource. China's economic vitality was stagnated at a low level for a long time, as well as agricultural mechanization level.

In 1966, "the 1st National Conference of Agricultural Mechanization" set the goals that agricultural mechanization should be fully realized by 1980 (Liu et al., 2008). The government treated it more as a political task, rather than an economic purpose. By implementing administrative means from central to local government, it achieved some level of agricultural mechanization. This goal, however, is impractical and far beyond both economic and technological conditions. The government cannot afford financial support of agricultural mechanization, it stagnated and then declined.

2.1.2 Stage 2. Adjusting and Stagnating (1978 to mid-1980s)

The "Reform and Opening-up" policy transformed China's economic system to a market-oriented economy, and greatly changed China's society. In the first few years of this stage, the policies and strategy of agricultural mechanization, which was inherited from the planned economy period, still affected the government policy and expenditures. Irrigated areas and the quantity of agricultural machinery were continuously expanding at a low rate (Liu et al., 2008). After 1980, the major policy reform, “household contract responsibility” policy, in the agriculture sector changed the operation of agricultural management from unified collective management to dispersed operation. In another word, each household of farmers got their “own” land, instead of working on large state-owned large farms with low income. This change offered farmers an incentive and opportunity to increase income and significantly encouraged agricultural productivity.

The average size of farm, however, suddenly decreased due to the dispersed operation, so the high-horsepower tractors or harvesters lost in use for small farmers temporarily when most of the national farm abandoned. As a result, there was not enough impetus for further agricultural mechanization. On the one hand, the government no longer directly invested in purchasing agricultural machinery or granting it to farmers. On the other hand, the primary purpose of farmers in this period was to improve life equality and reduce hunger. The obstacles to investing in agro-machinery or other inputs were limited savings and low income of farmers.

2.1.3 Stage 3. Transforming and Self-developing (late-1980s to mid-1990s)

The achievement of “Household Contract Responsibility” policy was significant after it had been implemented for years. It improved both income and saving of farmers. At the same time, urbanization and the growth in the manufacturing and service sector resulted in labor transfer, pulling labor out of agriculture. The opportunity cost of farming and labor cost in the rural areas made the farmers seek a substitution for human power. Thus, as perfect substitution of human labor, the demand for small agricultural machinery increased, and private companies in agriculture machinery industry began to emerge. Also, by more profound ownership reform (Liu et al., 2008), the private sector acquired some state-owned enterprises.

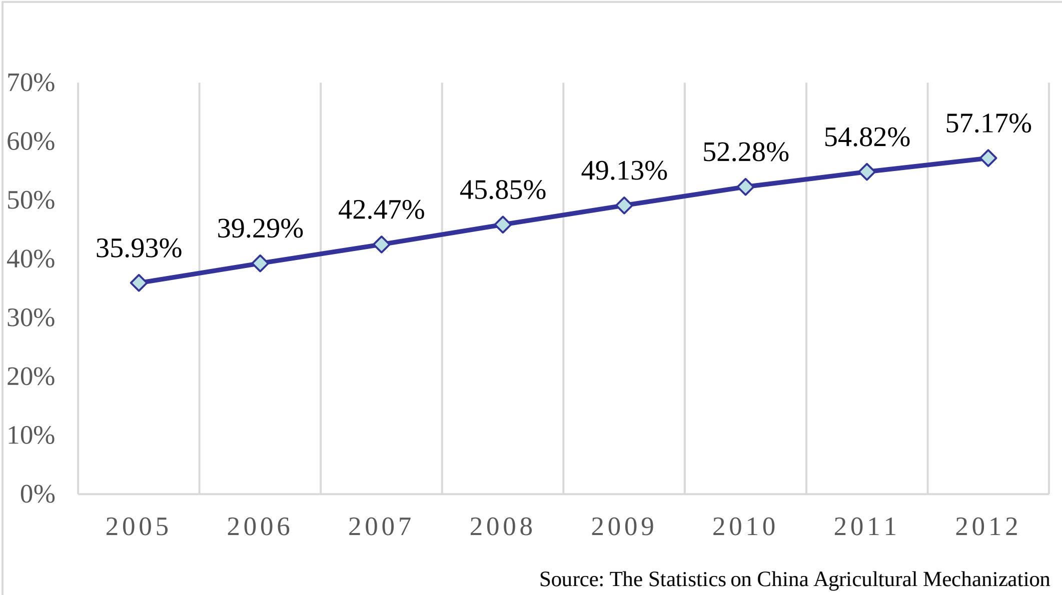
During this period, the government did not provide much support for the industry, only funding some critical research institutions of agricultural machinery and no direct subsidizing agro-machinery producing and purchasing. The increasing demand of farmers and the emerging private companies was the driving force of industrial growth. Compared with traditional state-owned enterprises (SOEs), the emerging private companies expanded higher autonomy. They rapidly introduced various models of small and medium-sized tractors, according to the demand of the rural market. Economic benefits and market power, instead of political goals, was the motivation for further development.

2.1.4 Stage 4. Public Supporting and Orderly Developing (late 1990s to now)

Starting from the turn of the century, this stage expresses economic vitality and strength from 20 years lasting of "Reform and Opening-up" policy. GDP, industrial power, and average personal income increased at a fantastic speed. The agriculture sector no longer was exploited as the cost of developing the manufacturing sector. The well-developed manufacturing sector started to nurture the agriculture sector in return. The market-oriented system had been integrated into every corner of the national economy, with no exception in agricultural mechanization.

The public sector only plays a guiding role, providing the purchase subsidies to expand domestic market demand, and offering more resources for leading companies to enter the global market. To accelerate development of agriculture, two leading policies were implemented in 2004 and 2006, “Law on the Promotion of Agricultural Mechanization” and “The 11th Five-year Plan for Agricultural Mechanization” (Department of Farm Mechanization (MOA), 2006; the NPC Standing Committee, 2004). The government mainly adopted the legislation to regulate the public support system and guide the agricultural mechanization process through a well-designed set of plans and policies. The detailed policies will be discussed from supply-side and demand-side in Section 2.3. Figure 2 shows the comprehensive agricultural mechanization rate in China from 2005 to 2012. The mechanization level is calculated by the weighted share of the land area which was operated by agricultural machinery to total agricultural land. The average mechanization level has exceeded 50 percent in 2010 and reached 57.17% in 2012.

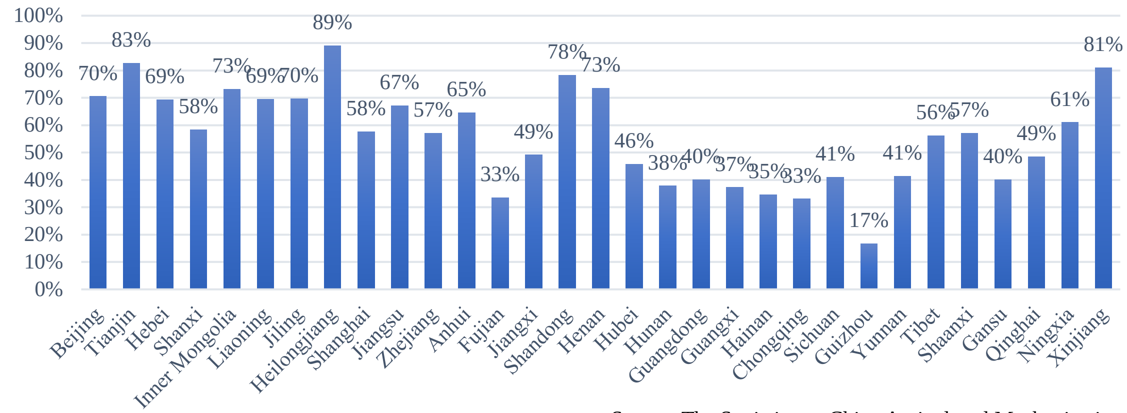
Figure 2 *The agricultural mechanization rate (%) in China (2005-2012)*



2.1.5 Imbalance in Recent Agricultural Mechanization

Although the agro-machinery industry is unprecedentedly booming and the mechanization level is continuously increasing, the imbalance in agricultural mechanization cannot be neglected. Imbalances can be shown in three aspects, including imbalance among provinces, imbalance among crop varieties and imbalance among operation stages. These imbalances indicate the weak points of recent development, and it also points out the future policy direction and potential markets (Li, 2008).

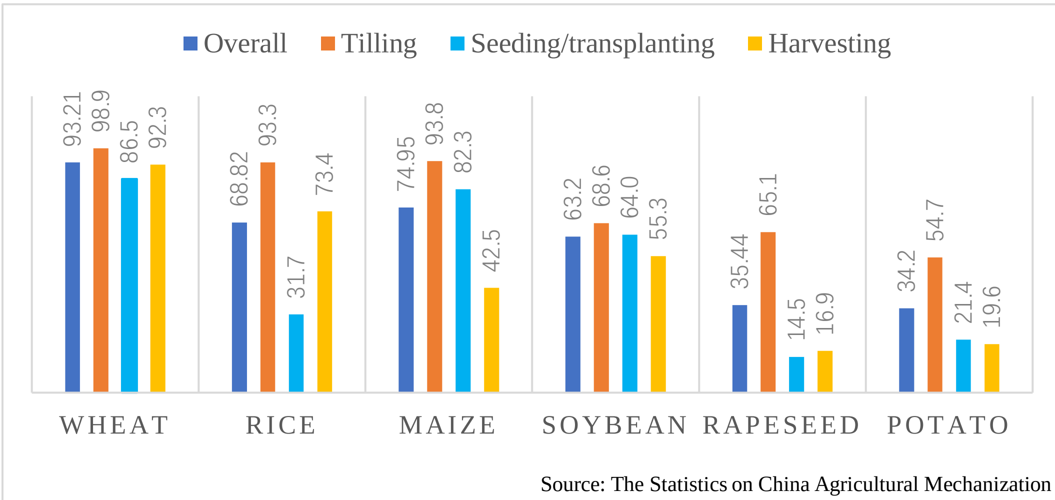
Figure 3 *The agricultural mechanization rate (%) for each province in 2012*



Source: The Statistics on China Agricultural Mechanization

Due to the provincial differences in economic capacity, average farm size and geographic feature, the regional imbalance is inevitable; however, it can be narrowed. Figure 3 presents the mechanization level for each province in 2012. Provinces with strong agricultural and industrial background tend to have higher mechanization level. In addition, geographic features also influence mechanization levels. North East China and Xinjiang province obtain larger farm size with easy-cultivatable soil, so it is easier to apply sizeable agricultural machinery, and the agricultural mechanization level reached a high level of more than 80%. Meanwhile, more economically developed provinces, such as Shanghai or Zhejiang province, have reached to medium-level of agricultural mechanization, around 50% to 60%. A favorable investment environment, well-constructed infrastructure, and beneficial tax exemption policies have attracted more investment in agricultural machinery. By contrast, provinces with a significant share of hilly terrain and less economically developed are less agriculturally mechanized. For example, in Guizhou province, the mountainous terrain has ruled out the possibility to apply large machinery, and the mechanization level is only 17%, the lowest level in China (DRC of Guizhou, 2013).

Figure 4 *The agricultural mechanization rate (%) among crops and operation stages in 2012*



Mechanization levels among different crop varieties are also uneven. The above Figure 4 presents the mechanization level of six main crops in three producing stages in 2012. Wheat, as one of the major crops, has almost entirely mechanized in the whole processing chain. The mechanization level of rice and maize is relatively lower and reached medium-level, above 60 percent. While other commercial crops, like rapeseed and potato, are still immature in mechanization, lower than 40 percent.

The mechanization level is not equal among three major operating stages for each crop. For rice, the transplanting stage is the weak point, and the mechanization level is only about 30%. The mechanization level in maize harvesting is only 42.5% in 2012, about half of the other stages. For rapeseed and potato, tilling stages are comparatively higher, exceeding 50%, while seeding and harvesting stages are still stagnating at a low level.

2.2 Recent Agricultural Machinery Industry

2.2.1 Industry Performance

In the past five years to 2015, the industrial main business income has increased at an average rate of 13.3% annually to 449.2 billion CNY (Department of Farm Mechanization (MOA) & Research Center of China Agricultural Mechanization Development (CAU), 2016). The growth was primarily driven by the strong domestic demand for agricultural inputs, high agricultural products price, increasing export volumes, and consistent government assistance with subsidies and favorable tax policies.

The total industrial profit gradually rose to 27.65 billion CNY in 2015, while the profit increase rate fluctuated each year. From 2014 to 2015, the total profit increase of 10.1%. By contrast, from 2013 to 2014, the total profit only increased by 2.9%. Many reasons may contribute to this fluctuation. Frequent fluctuation in raw material price and dynamic demand of the global market are widely considered as the major reasons. In following serval years to 2020, the profit rate tends to remain low due to the rapid growth in labor cost, especially for wages of skilled workers.

Table 1 *Key statistics of Industry Performance from 2011 to 2015*

Year	**Main Business Income (Billion CNY)**	**Main Business Cost (Billion CNY)**	**Total Profit (Billion CNY)**	**Total Tax (Billion CNY)**	**Number of Companies (firm)**
2015 Increase rate	449.42 (7.75%)	383.99 (7.75%)	27.65 (10.10%)	-	2510
2014 Increase rate	417.09 (10.35%)	356.37 (11.10%)	25.12 (2.90%)	8.75	2428
2013 Increase rate	377.98 (16.26%)	320.76 (18.18%)	24.4 (9.40%)	9.44	2154
2012 Increase rate	325.12 (25.99%)	271.51 (25.75%)	23.89 (26.12%)	11.39	2076
2011	258.05	215.91	18.94	-	1783

Source: Yearbook of Agricultural Mechanization Industry

From Annual Statistics of Industrial Firms (ASIF) data, in 2009, Herfindahl index (HHI) of agro-machinery industry, which is a widely used method to evaluate competition intensity in one industry, is only 0.0549 (549 points), increasing from 0.0366 (366 points) in 2006. The HHI is lower than 0.15 (1500 points), meaning that it can be classified as "low concentrated" industry, according to the definition of the antitrust division in the U.S (Shapiro, 2010) .

The number of companies has risen from 1,783 to 2,510, reflecting an annualized increase of 5.22%, from 2011 to 2015. However, most of the operators are small-scale domestic privately owned. These companies can only provide limited varieties of products with low quality. Facing more intensive market competition in the future, they are more likely to crowd out. The products with better performance and quality will help companies to survive and take a larger market share. At the same time, market leaders continue to expand their market share and extend business even to the international market. For example, Foton-Lovol, a leading company in China, has taken 70% share of the combined harvester market and has established an extensive business network with hundreds of distributors all over the country (IBISWorld, 2018). In short, to be a winner, essential success factors are better quality control, economies of scale, extensive distributor network and a highly skilled workforce.

2.2.2 Globalization

Regarding international trade, exports keep increasing but remain at a small volume, while import volume fluctuated in the past the five years. Exports contributed 7.18% of total industry revenue in 2015 (Department of Farm Mechanization (MOA) & Research Center of China Agricultural Mechanization Development (CAU), 2016). Small-scale farming equipment and its accessories used to have the major share in exports. Their share is, however, continuing to decrease, and the share of high-end products increased in the past five years, due to improved technology abilities of domestic manufacturers. At the same time, technology innovation improved the products' performance and their prices.

Compared with other primarily agricultural input industries like fertilizer industry or pesticide industry, the agro-machinery industry has a relatively low barrier for foreign capital and world "best in class" companies to enter the Chinese market. Four of the top ten companies in China's market are foreign-owned or joint ventures from three different countries, including Kubota (Japan), John Deere(U.S.), Yanmar (Japan) and Tongyang (Korea) (IBISWorld, 2018). According to versions of "Catalogue for the Guidance of Foreign Investment Industries" from 1995-2017 (Ministry of Commerce, 2017), nearly all types of agricultural machinery have been on the "Encouraged industries" list since 1995. The "Encouraged industries" has beneficial policies including lower tariff, land concession, and lower income tax rate (Ministry of Commerce, 2017). From the share of investment source (Table 2), the total share of capital from foreign countries or overseas (Hongkong, Macao or Taiwan) is 10.7%, which is even higher than the share of state-owned capital. The share of domestic private capital is still the highest part of the total investment.

Table 2 *Sources of Industry Investment in 2015*

	State capital	**Collectives capital**	**Legal persons capital**	**Individuals capital**	**Hong Kong, Macao and Taiwan capitals**	**Foreign capital**	**Total**
2015: Billion CNY	3.52	0.71	22.83	30.16	1.62	5.22	64.06
Share %	5.5%	1.1%	35.6%	47.1%	2.5%	8.2%	100%

Source: The Statistics on China Agricultural Mechanization; Unit: Billion CNY

The high levels of foreign investment can provide more opportunities in technology introduction. To access domestic market strategic support or higher economic scales, the joint venture is the most popular type for foreign companies to enter China. The advanced technologies from developed countries like the U.S., Japan or Korea, are introduced into

China by establishing joint ventures with domestic players.

For domestic companies, a high level of globalization offers not only challenges form intensive competitions but also rich opportunities. Domestic industry giants, either state-owned private owned, are seeking chances to establish global marketing channels and grasp world-leading technology through overseas acquisition. It will be further discussed in Section 2.4.2. It seems that we can be optimistic to predict higher globalization and higher imports/exports value in future.

2.2.3 Future Development

In the future, further government subsidies, machinery upgrade demand, and rising food price will stimulate the total demand for agricultural machinery and ongoing growth space for industry. To meet the extending domestic demand for machinery, enterprises must improve product features, enlarge varieties of products and provide better After-sale services. From the cost aspect, increasing wage of skilled worker and fluctuating raw material prices lead to higher total cost. It requires strict cost control and efficiency resource use. Exporters need to face the risk of currency exchange rate as well. VAT reform will ease the burden of tax cost, stimulate fixed assets investment and increase demand from machinery rental service companies.

Thus, improving investment in R&D and extending distribution network can be the critical factors to improve business performance. Companies with cutting-edge software and breakthrough in positioning and accurate technology can provide better products and service for farmers to increase productivity and profit. What is more, the energy saving technique and production methods should be introduced into the industry to meet the high requirement of new environmental regulations.

2.3 Agricultural Machinery Related Policy

Government support has a significant effect on the industry, benefiting both supply and demand side of the industry. To transform and restructure China to an innovation-oriented economy, industrial policies were designed by central and local level, including tax incentives, public subsidies, free or low-cost loans, subsidized industrial inputs and preferential land use (Haley & Haley, 2013). The following table provides a list of related policies of agricultural machinery industry.

Table 3 *Related Policies of Agricultural Machinery Industry*

Published Year	National Strategy
2006, 2011, 2016	The 11th-13th Five-year Plan for Agricultural Mechanization Development in China
2015	Made in China 2025
Demand Side	
Tax Policies	
2006	Abolishing the Regulation of the People's Republic of China on Agriculture Tax
2016	Pilot Program of Replacing Business Tax with Value-Added Tax

2017	Relevant Policies on the Streamlining and Combination of Value-added Tax Rates
Subsidies	
2004	Law on the Promotion of Agricultural Mechanization
2004-Now	Guiding Opinions on Implementation of Agricultural Machinery Purchase Subsidy
2012-Now	Guidelines of the Pilot Projects Implementation of Scrapping and Updating Subsidy for Agricultural Machinery
Supply Side	
Tax Policies	
2004	Regulations on Several Issues of the Expansion of VAT Deduction Range in Northeast China
2017	Provisional Regulations on Value-Added Tax (2017 version)
Technology Policies	
2011	The 12th 5-year Plan of National Agricultural Mechanization Promotion
2012	Law of the PRC on the Popularization of Agricultural Technology
Export Policies	
2008	Increasing the Export Tax Rebate Rates of Value Added Tax on Labor-intensive Commodities
1995-Now	Catalog for Guidance of Foreign Investment Industries
Restrictions	
2014	Environmental Protection Law of the PRC (2014 version)

Source: The National People’s Congress, The State Administration of Taxation, Ministry of Agriculture, Ministry of Industry and Information Technology, Ministry of Business

2.3.1 Demand-Side Policy

The demand side policy provides indirect support for the agro-machinery industry. Agriculture tax reform, price support for crops and agricultural machinery purchase subsidy are major policies in demand side. Cancellation of agriculture taxes and price support for crops provides indirectly supports for the industry, through improving farmers purchasing power, thus encouraging farmers to invest more in agricultural input and fixed assets (the NPC Standing Committee, 2006).

The history of agricultural machinery purchase subsidy can trace back to 1998. With a limited quantity of large tractor and decreasing tillage capacity, central government allocated 20 million CNY to subsidize purchasing large tractors, and implements start from 1998 (Li, 2008). The overall farm machinery purchase subsidy framework nowadays is designed based on the experience of specialized large tractor subsidy in limited provinces from 1998 to 2003 (Li, 2008). The turning point in China agriculture subsidy policy is 2004. In 2004, China introduced its first national direct subsidies to farmers, began to subsidize agricultural input including seed and machinery purchases, and boosted national funding for agricultural infrastructure and research (Gale, Lohmar, & Tuan, 2005). Also, China passed the law on agricultural mechanization and allocated 70 million CNY to subsidize purchases of farm machinery in 66 large grain-producing counties of 16 provinces. Subsidies can cover up to 30 percent of the purchase price (the NPC Standing Committee, 2004).

The amount of subsidy, the area of implemented regions, and the range of subsidized products kept increasing in the following years. The machinery purchase subsidy almost doubles or triple each year from 70 million in 2004 to 13 billion CNY in 2009 (Department of Farm Mechanization (MOA) & Research Center of China Agricultural Mechanization Development (CAU), 2016).The level of purchase subsidy reached the peak in 2012 and stayed the at around 20 billion each year until today. Regarding subsidized area, all agricultural county over China showed up on the list of funded regions until 2008 (Ministry of Agriculture & Ministry of Finance, 2007). Also, the category of subsidized products expanded to 12 classes with 48 subclasses involving every process of all agriculture products. (Ministry of Agriculture & Ministry of Finance, 2008) In 2012, a machinery replacement program was added to the subsidy system, filling up the upgrading need for more advanced technology for farmers. (Department of Finance (MOA), 2012)

The purchase subsidy shifts down the barrier of machinery investment for farmers, increase and create demand for agricultural inputs and hence the agricultural productivity. In the national strategy perspective, the purchase subsidy encourages the adjustment of agricultural structure, raise self-sufficiency in terms of food security, and spur rural-urban transfer and urbanization.

2.3.2 Supply-Side Policy

From the supply side, there are restrictions and incentives. For restrictions, firms must meet the high environmental requirement of both central and provincial government according to the newly released environment before any operations. The new environment law aims to deal with air, water, and waste emissions, as well as hazardous materials and chemicals (the NPC Standing Committee, 2014). It increases both the cost and needs of green producing technology. At the same time, it is also an opportunity to squeeze out companies with low technology and inefficient management and upgrade the whole industry.

For encouraging policies, production-based subsidies and value-added tax (VAT) reforms are main factors to the manufacturers. The production-based subsidies include subsidies according to sales quota or workload, VAT rebate and export tax rebate. The production-based subsidies in China are arranged for firms to encourage indigenous innovation or high-tech products, although the precondition of which company can receive a production-based subsidy is unclear. The policymakers tolerate a lower efficiency of those state-backed companies to encourage them to transform into successful innovators and generate larger social welfare (Howell, 2016b).

To encourage exports and expand business in the global market, the Ministry of Finance and State Administration of Taxation increased export rebates on some types of agricultural machinery. For instance, horticultural machinery, roller presses and combine harvesters were added to this list, with 26% export rebates. (State Council of PRC, 2017) It further eased the taxation burden of agricultural machinery companies. For imports, the Chinese government did not set up any barriers to foreign products to create an unfair domestic competition environment, such as imposing a high tariff to protect domestic companies. Furthermore, many imported products still benefit from the low tariff rates if its production country is on the list of “Most Favored Nations Treatment” from WTO.

The value-added tax is one of the major taxes in China, which is a tax on the added value amount at each stage of the supply chain. The VAT transformed from production type to consumption type, starting from 2004 and expanding to the whole country in 2006, which means that fixed assets investment can be considered as a deduction (State Administration of Taxation, 2004, 2006). Thus, it will inspire manufacturing companies to invest more in fixed assets. What is more, in 2014 and 2017, the value-added tax rate in this industry drop from 17% to 13%, then now to 11% (State Council of PRC, 2017) . This policy not only reduced the tax burden but also induced some companies, especially the large manufacturers to advocate complementary separation in a certain extent, to adjust the structure of company structure and focus on resource efficiency.

The Chinese government also implemented policies to encourage companies' indigenous innovation capacities and trigger upgrade industry upgrading. Policies at the central government level provide support mainly through funds. Policies include National Natural Science Funds and National Key Research and Development Program to encourage fundamental innovation. For applied innovation, the government has funds for National Science and Technology Major Project and Technological Innovation Guided Special Fund (can be applied after achieving R&D outcome).

At the provincial and prefecture levels, although policies support of scientific research is weaker than the central government, there are more diversified policies approaches to reach the multiple aims. The primary purposes of these policies are to retain companies, create job opportunities, and increase tax revenues. Talent programs have been carried out, such as the Start-up and Innovation Talents policy in Jiangsu province. The government will provide funds for both recruiter companies and employed talents. In other aspects, there are policies providing tax reduction, land use benefit, tax rebates and so forth.

2.4 The Innovation System of Agricultural Machinery Industry in China

The public R&D has long been an essential driver for developing new technology and innovation, as well as extension in the agricultural sector. The institutional structure of public R&D in the United States consists of four levels: 1) universities focusing on basic and applied research, 2) state agricultural experiment stations and the USDA institutions focusing on strategic or generic research, 3) state experiment stations and private companies focusing on applied research, and 4) extension system and private companies disseminating new technologies (Pray, 2001). China has different institutional structures for both public and private R&D. Different from the discipline-based public R&D system in the U.S., China has a multilevel institutes-based public R&D system, which is affiliated to the central and local government. China's public R&D system take overall responsibility for basic research as well as technology transfer and dissemination. For the private sector, the domestic private companies mainly focus on applied research and applications, while the state-owned enterprises (SOEs) may engage in both basic and applied research. Foreign companies and joint-ventures also make their unique contribution to technology innovation through technology transfer and “spillover” effects.

2.4.1 Public R&D for Agricultural Machinery in China

Public R&D sectors for Agricultural Machinery in China, in general, can be divided into three levels, including national, provincial, and prefecture/county-levels.

Sponsered by fundings from central finances, national-level R&D institutions are established by joint efforts of multiple ministries, including Ministry of Agriculture (MOA), Ministry of Industry and Information Technology (MIIT), and Ministry of Education (MOE). These institutes focus on basic research for industrialization and consulting service for policymaking. Back to the 1950s to 1960s, most scholars and talents of national public R&D institutes for agricultural machinery had experience of studying or working abroad in the Soviet Union or the United States.

Provincial-level R&D institutes are funded by and affiliated with the provincial government. They mainly focus on applied research and application. The research field of each province depends on their geographic features, natural resources as well as the main or featured crops. For example, Guangdong province is located at low latitudes area, affected by the tropical monsoon climate. Therefore its institutes mainly target the processing machinery for tropical foods (Department of Agricultural of Guangdong, n.d.). Although each province owns their own R&D institutes for agricultural machinery, their research capacity varies significantly due to differences in economic capacity, past research experiences, and local industrial clusters. Specifically, R&D institutes in Heilongjiang, Shandong, Jiangsu provinces are more developed compared with those in the rest of the nation.

The prefecture or county level R&D institutes only focus on the extension, application, as well as inspection of agricultural machinery. The county-level multipurpose technology institutes consist of different stations for seeds, machinery, inspection, and others to an extension institute.

2.4.2 Private R&D for Agricultural Machinery in China

In this study, the private sector includes not only private companies but also state-owned, or state-controlled enterprises, considering they are all product suppliers in the market. Private R&D mostly focus on applied research, aiming at improving manufacture efficiency and reducing costs. Private R&D is concentrated among several large companies, including First Tractor Co. (YTO), Foton-Lovol, John Deere, and Kubota. Most private companies choose technology acquisition and transfer rather than own research as the major resources of achieving new technologies. From "Opening-up" policy, the increasing foreign direct investment (FDI) provide more opportunities for introducing better technologies in Chinese industry. The R&D investments of foreign companies are, however, based only on the Chinese markets but also their markets outside China.

With better resource, capital and policy support from the central and provincial governments, SOEs are more likely to have financially capable of investing in and more willing to engage in R&D activity. For instance, the First Tractor Co. (YTO) greatly improved its research capacity by acquiring the Luoyang Tractor Research Institute in 1994. Chinese government established this institute in the 1950s, initially focused on the reverse engineering of technology from the Soviet Union in 1950s to 1960s (Luoyang Tractor Research Institute Co., n.d.). In 1994, it was merged into YTO, one of the biggest agro-machinery companies in China. In 1995, it was further merged with the Tractor and Automobile Research Institute of YTO and became the core R&D institute of YTO. What is more, due to the SOE reform start in the 1990s, many research-oriented institutes were transformed into market-oriented state-owned enterprises with multifunction. For instance, the Chinese Academy of Agricultural Mechanization Sciences (n.d.) was a central-level research institute, founded in 1956, affiliated to Ministry of Machinery Industry. It was restructured to large high-tech SOE with both research-purpose and profit purpose. Its subsidiary companies, such as Modern Agricultural Equipment co., are responsible for process and sales (Chinese Academy of Agricultural Mechanization Sciences, n.d.) .

For domestic private companies, superior policy environment and rapid growth in domestic demand attract new entrants from other machinery manufacturing industries. At the same time, intensive competition and saturated market in their original industries force these new entrants to transform and expand into new industries. Most of the new entrants came from the construction machinery, earth-moving machinery, and automobile industries.

The entrance of new players forms other industries led to the introduction of more advanced processing technique to farm machinery industry and dramatically improved productivity. New entrants also led to the relocation of industry clusters.

The industrial agglomeration shows “follow-the-leader” pattern. For instance, hundreds of small or medium-sized producer-service suppliers and accessory manufacturers followed YTO, locating at Luoyang city, turning it to an industrial cluster. The Weifang in Shandong province was led by Foton-Lovol, a top-notch company in farm machinery and construction machinery industry, surrounded by upstream and downstream firms.

Inward foreign direct investment displayed “spillovers” effect on domestic firms, positively impacting on overall regional innovation capacity. With the help of foreign advanced technology and management philosophy, the domestic industry narrowed the technological gap with world-leading companies. In addition, entry of foreign companies has an oversight role in promoting the technological upgrading of local enterprises. In the competition with advanced products from foreign companies, the domestic companies must focus on the quality and performance of products to compete for higher market share. The outward foreign direct investment works as a new way to encourage innovation over recent years. The leading domestic enterprises try to enhance its high-end products and launch global expansion through overseas acquisitions. For instance, YTO has acquired a French company, Saint-Dizier, and established an industrial and R&D complex for Europe in 2011 (YTO France, n.d.). From 2011 to 2015, Foton-Lovol launched a major acquisition plan, taking over Arbos and consolidating with MaterMacc and Goldoni in Italy, aiming to conduct research enter the global high-end agricultural equipment market in Europe and elsewhere (Arbos, n.d.).

2.4.3 Public-private innovation collaboration

Public-private research collaboration has been growing in the past decade. There are typically four ways of cooperation: (1) institutes transferring technology or arranging technical support to companies, (2) institutes delivering business consulting services, (3) company providing prototype or processing services, (4) institute and companies applying for research funds or projects jointly.

The following cases from Nanjing Research Institutes of Agricultural Mechanization (NRIAM), a central-level research institute, represent common forms of public-private research collaboration.

Founded in 1957, NRIAM developed the world's first mechanical power rice transplanter. For now, it has obtained more than 1,300 knowledge achievements and over 100 patents, including cotton harvester, peanut harvester, tea dryer, rape harvester, etc. (Nanjing Research Institute for Agricultural Mechanization, n.d.-a). Over recent years, it grows into a pacemaker of cutting-edge technology and research in domestic industry, like crop protection drone. Composed of departments with diversified research area, collaborators of NRIAM covers top-tier companies in the industry, including SOEs like YTO and Zoomlion, domestic private companies like Foton-Lovol and Jiangsu World Group or foreign players like KUBOTA and YANMAR (Nanjing Research Institute for Agricultural Mechanization, n.d.-b).

Technology transfer is always the first choice for NRIAM in collaboration, considering high risk of patent infringement and high legal cost. NRIAM choose to receive a one-time charge of royalties instead of technology licensing in the long run. Although China's patent protection system is continuously improving, the punishment of intellectual property violation is not heavy enough. At the same time, due to lack of trusted certificate authorities, it is difficult to define copycat and infringement. Therefore, companies will burden all the infringement risk for research institutes, give up prosecuting copycat and just invest more in business strategy to get a higher market share to achieve short-term profit. In cooperation with foreign enterprises, like KUBOTA and YANMA, NRIAM focus more on small and medium-sized agricultural machinery, taking advantage of its rich experience in rice, rapeseed, and peanut machinery. Recently, its business has been expanded to designing large farm machinery, such as cotton harvester special for Xinjiang geographic condition (Nanjing Research Institute for Agricultural Mechanization, n.d.-b).

As for consulting service, clients of NRIAM are usually new entrants from engineering manufacturing or other industries. NRIAM will provide competition analysis, industry prospect or other strategy reports for them.

What is more, collaborations in research within public research institutes are quite common. Taking advantage of strong aircraft research background in Nanjing, NRIAM chose to co-operate with the Sixtieth Institute of the General Staff Department, a spacecraft and aircraft research institute of Ministry of Defense, for the joint design of plant protection drones (Agricultural Resources and Market, 2018). The hardware of the aircraft was completed by the aircraft research institute, while the software and spray methods were designed by NRIAM.

2.5 The General Role of Public and Private R&D in Agricultural Innovation

Although the world population was almost tripled after the WWII, the global food production can still meet the rapid growth of food demand due to the agricultural productivity growth. The technology development has always been the major factor in shaping agriculture (Cochrane, 1979; Schultz, 1964). In addition, the R&D investment from public and the private sector in food and agricultural research greatly contribute to the agricultural productivity improvement (Piesse & Thirtle, 2010).

For the public sector, food safety is a basic and critical issue. Small-scale farms are the major components in the agriculture sector historically, and it takes long gestation periods to achieve full benefits from the agricultural R&D investment. Therefore, the public sector has provided funds and resources to agricultural R&D for a long time, helping to solve the high risk and long-term issues in agricultural R&D. In both developed and transitioning economies, a national agricultural research system (NARS) is a key approach to produce a steady stream of innovation outputs and ultimately to improve agricultural productivity. As a top-notch country in agricultural technology, the federal government of the U.S. continuously funds agricultural research programs, including crop and livestock production and protection, human nutrition, food safety and so forth (Fuglie & Toole, 2014). For transitioning countries such as India, the NARS helps to induce advanced technologies to local farming systems and further improve productivity and lower food prices (Pingali, 2012).

Companies based in developed countries finance approximately 95% of global expenditure on private R&D but there are still global research networks and joint-ventures to transfer technology to developing countries and emerging market (Fuglie et al., 2011). In the U.S., the private sector R&D system focuses on fewer areas than the public sector, such as on food, crop seed, chemicals, and farm machinery (King, Toole, & Fuglie, 2012). In India, Multinational corporations play an important role in agricultural inputs industries and provide a large share of private R&D. By contrast, in China, due to the regulatory and limitation of FDI, multinational corporations play a smaller role (Pray & Fuglie, 2015).

The relationship between public and private agricultural R&D are either “complements” or “substitutes” patterns (David, Hall, & Toole, 2000; Toole, 2007). They are complementary when public R&D conducts research which can stimulate additional private R&D investment; substitution happens when public R&D with public funds conducts research which would have been financed by the private sector (Fuglie & Toole, 2014). Fuglie and Toole (2014) summarized nine empirical studies using time-series or multilevel cross-sectional data, and find that seven out of nine studies in the U.S. and China supports the complementarity, while the other two studies support "crowding out" relationship in U.S. and Europe.

Both structure and financial changes have been taken place in the agricultural input industries, such as seeds, chemicals, and machinery. In the past three decades, the worldwide private R&D spending has been rising faster than the public R&D expenditure (Pray & Fuglie, 2015). From 1981 to 2000, the growth rate of private sector expenditure on food and agriculture R&D is almost three times than the rate of the public sector in OECD countries; what is more, in OECD countries, the private sector expenditure in R&D has taken up 54% of total food and agricultural R&D, by 2000 (Alston, 2010). At the same time, the public expenditure on agricultural R&D has been decreasing, which may lead to crop yield decline since 1990 (Alston, Beddow, & Pardey, 2009). Fuglie (2012) points out that biotechnology breakthrough, globalization of food and agricultural markets, intellectual property protection and regulatory policies changes are the driven factors inspiring private sectors to invest in agricultural R&D worldwide.

The R&D expenditure growth in the private sector varies across agricultural input industries. In the sample of the U.S. agricultural research history, until 1980, machinery and chemical inputs were once the two major areas where most private agricultural-related research was focused; however, by 2010s, crop seed and biotechnology R&D became the dominant component in private agricultural R&D (Fuglie & Toole, 2014). Across food and agricultural technology fields, the private sector has recently been providing 55% in plants research, 25% in animals, and 84% in farm machinery and engineering (King et al., 2012).

The global agricultural input industries are undergoing rising market concentration. A few agricultural input companies conduct most of industry R&D spending and own most of the relevant intellectual property, which constitutes a significant barrier to new entrants and may reduce investment in the low-profitable areas (Fuglie, Heisey, King, Pray, & Schimmelpfennig, 2012). the opening of markets in China, India, and Brazil has, however, attracted more participant, increased competition and attracted more R&D investment. It also provides opportunities for Chinese firms to expand their markets and invest in R&D to win more market share globally (Pray & Fuglie, 2015).

SECTION 3 LITERATURE REVIEW

Since innovations theory of Schumpeter, Salin, and Preiswerk (1950) argued that technological change and innovation are crucial to the market economy, the importance of innovation to firms and economy has gotten increasing attention from economists and policymakers. Through technological developments and creating innovation, firms can introduce new products, reduce process cost, and increase their market shares. Policymakers fund R&D to ensure the sustainable economic growth and development of the country. Therefore, the mechanism of R&D investment decision, innovation production, and influence of innovation on productivity are put forward as a critical topic in economics.

3.1 Determinants of R&D Investment

There are masses of literature focusing on R&D. Most of the studies show interest in the determinants on R&D expenditure and R&D investment decision. Therefore, previous studies illuminate the potential determinants for this research.

The public funding is a common tool for policymakers in many countries to inspire R&D activities in the private sector. Knowledge has the characteristic of the public goods. The external effects of knowledge cannot be entirely internalized by companies, so R&D investment for the private sector alone is likely to below the optimal level. Arrow (1962) indicates that public funding can overcome the market failure. Dozens of literature shows the public subsidies can encourage firms to increase R&D investment (Aschhoff, 2009; Czarnitzki & Hussinger, 2004; Hussinger, 2008). In comparison, other studies find the “crowding out” effect of public subsidy. For instance, Wallsten (2000) shows that the U.S. SBIR program crowds out private R&D investment of subsidized companies.

In addition, the public sector also carries out R&D directly and conducts an appreciable share of R&D activities. Eurostat (2009) points out that, from the mid-1990s to mid-2000s, the public share of R&D activities was about 30% in the U.S., 35% in the EU27, and 18.5% in Japan. A number of economists indicate the complementarity between public and private R&D, For the agricultural sector in the U.S., S. L. Wang, Heisey, Huffman, and Fuglie (2013) provide evidence that public and private R&D are complementary and both sector responses to each other’s activity. In addition, the public/private technology partnerships offer an opportunity for companies to participate and tend to stimulate R&D in the U.S (Audretsch, Link, & Scott, 2002).

As for firms’ attributes, the firm size, measured by sales or number of employee, is the most common firm-level factor according to the variable selection of past research. Vast literature report positive effects of firm size on R&D investment probability in well-developed countries, like U.S., Italy, France, Germany and in developing economies, like India, Hungary (Cohen, Levin, & Mowery, 1987; Griffith, Huergo, Mairesse, & Peters, 2006; Kumar & Saqib, 1994; Urem, 1999). In addition, the square of firm size is also an important variable, widely used in many research. These research reveal a common finding that the firm size tends to show positive influence on R&D investment, while the square of size has negative effects (Costa-Campi, Duch-Brown, & Garcia-Quevedo, 2014; Kumar & Saqib, 1994; Segarra-Blasco, 2010).

Furthermore, capital intensity represents the relationship of capital, mostly fixed capital, to other factors of production. The most frequent measurement is the ratio of capital to labor cost. Previous works indicate that capital intensity can be a prominent feature positively affecting R&D investment (Siddharthan & Agarwal, 1992). However, the high requirement of average capital intensity in some high-tech industries can also be a barrier for indigenous innovation (Powell et al., 2015).

Since the research of Coe and Helpman (1995) presented that evidence that knowledge and technology can spill over across country borders through trade flows and foreign investment, the effect of foreign investment on domestic R&D has become one of the major concerns in the R&D literature. The firm’s ownership structure can be an essential factor in a firm’s innovation investment. For example, You, Chen, and Holder (2010) report that in the Korean pharmaceutical industry, the share of foreign ownership is positively related to R&D intensity, while in the U.S. there is little evidence about the association between R&D intensity and ownership structure. Simliarly, Lee and O'neill (2003) find that the ownership structure shows distinct patterns on R&D investments in Japan and the U.S. What is more, Braga and Willmore (1991) indicated foreign ownership and public ownership variables in their research about Brazil are insignificant. In China, SOE was the only ownership type in the planned economy period. However, different ownership types emerged in the past two decades as the result of the restructuring of SOEs and the deregulation of private and foreign investment entry. Therefore, the ownership structure has to be concerned given this historical background.

3.2 The Influence of R&D on Innovation

R&D activity for firms usually serve two purposes and will both eventually affect firms' innovation. The first purpose is to invent new products or a new process, by carrying out research projects. In most of the time, innovation plays the intermediate role in R&D activity and the firm's ultimate goal which is to improve economic performance. The innovation outputs are conventionally measured by the number of patents. Bound, Cummins, Griliches, Hall, and Jaffe (1982) reports the strong relationship between two activities, R&D and patent, by estimating panel data of 2600 manufacturing sector firms in the U.S. Hall, Griliches, and Hausman (1984) further confirms the significant relationship between R&D and patenting, while no long-time lag presents in this process.

However, from the study of Griliches (1998), the aggregate patent number has grown more slowly than R&D investment and diminishing returns in "knowledge production function" was observed. In addition, Pavitt (1985) and Griliches (1998) doubted the relevance of applying patent statistics as indicators of economic performance and R&D

activities. Since there still part of innovation cannot be patented, the share of sales by new products is considered as an alternative indicator of innovation outputs by taking unpatented products into account.

The sales of new products or products produced by new processes as an indicator of innovation are becoming more popular in recent studies. For example, in the study of overall Chinese industry, Jefferson, Huamao, Xiaojing, and Xiaoyun (2006) chose the share of sales by new products or process as the indicator of innovation output, and find that it is strongly associated with R&D investment intensity. Lööf and Heshmati (2002) also indicate that knowledge capital, estimated by the ratio of innovation sales to total sales, increases with innovation investment, based on European CIS data.

The other purpose of R&D activity is to enhance the absorptive capacity of introducing new technology. If R&D projects are unsuccessful and no innovation outputs are achieved, technology transfer is the alternative option to improve a firm's performance. In this situation, engaging R&D can still benefit firm to improve the efficiency and speed of technology introduction by increasing firm's capacity to absorb and understand new knowledge (Griffith, Redding, & Van Reenen, 2003).

3.3 How Innovation Impacts Productivity

In the work of Mohnen and Hall (2013), they combed through the detailed process of how innovation affects productivity. Products innovation and process innovation are the two most common types of innovation outputs; however, they affect productivity through different paths. New products entering into a market will stimulate new demand. It will further lead to the increase in the economics of scale, therefore give rise to the productivity. It is worth mentioning that the opposite consequence may happen when new products have a complementary effect on the old products. The complementary between new and existing products may cause the stagnation of demand increasing, even the shrinking of scale economies.

Process innovation intuitively affects the productivity positively. Process innovation directly affects productivity by reducing the cost of all kinds of inputs, including material and labor. Also, there is an indirect effect of cost decrease. The cost decrease allows companies to reduce their product price and implement more aggressive marketing strategies, such as reducing products price, which further improves the demand from consumers and expands the economy of scales, and finally result in improving productivity.

Many previous studies report a positive association between innovation outputs and the firm's productivity in economies with mature markets and countries in transitioning. For instance, Lach (1995) utilize patent counts as the proxy of innovation outputs to estimate its contribution to firm-level total factor productivity, then find that the productivity elasticity of knowledge is around 0.3, in U.S. manufacturing industries from 1959 to 1986. In a transitioning economy, the research of (Chudnovsky, López, & Pupato,

2006) on Argentine manufacturing firms finds a significant positive impact of process innovation on firms' productivity. What is more, it's worth mentioning that the depth of innovation novelty will affect the strength of the association between innovation and firms' productivity. Jacques Mairesse, Mohnen, Kremp, and KREMP (2005) show that in a high-tech industry, products new to firms have lower influences on productivity than products new to the industry, while this relation is reversed in low-tech industry.

However, innovation does not always result in productivity growth. For example, the study of Mansury and Love (2008) on U.S. business services reveals that innovation is consistently associated with firm growth positively, but there is no significant effect on productivity. In addition, comparing four European countries, Griffith et al. (2006) show that although systems of innovation and productivity are similar, the influence of innovation outputs on productivity varies among the four countries.

3.4 The CDM Structural Innovation Model

From the early 1960s, numbers of studies focusing on the relationship between innovation and company performance. The pioneer work of Griliches (1979) provides the theoretical basis for the following studies. He pointed out various lag structures between R&D expenditure and productivity growth and addressed that the R&D expenditure should be treated as inputs rather outputs in a firm's innovation. The research of Pakes and

Griliches (1984) introduced the number of patents, as the innovation outcomes indicator, measuring the new knowledge capital from R&D expenses to affect economic performance.

Based on the previous researches, most of the recent studies focusing on the linkage of R&D investment, innovation and productivity have done so within the Crepon-Duguet-Mairesse (CDM) model, which was originally developed by Crépon, Duguet, and Mairessec (1998). It constructs a systematic innovation framework with three-stage knowledge production functions linking the knowledge input, output, and firm performance, and implying the positive relationship between them. The original CDM model is formalized in four equations: (1) the firm's decision in invest in R&D activities; (2) the intensity of R&D investment for firm's which has made decision; (3) knowledge production function to measure how much knowledge output is generated from R&D investment; (4) the output production, link the knowledge as input to firms' labor productivity.

This framework has been employed for both developed country (e.g., France, Germany, Netherlands, Italy and so forth) and developing countries (e.g., China and Chile) (Griffith et al., 2006; Jefferson et al., 2006; Lööf, Heshmati, Asplund, & Nåås, 2001). These studies modified the original CDM model to accommodate their choices of endogenous variables and exploit the unique features of their individual data. The majority of studies undercover positive associations between R&D investment, innovation output, and firms' performance in the context of advanced and leading industrialized economies (Galia &

Legros, 2003; Janz, Lööf, & Peters, 2003) and emerging and newly industrialized economies (Aw, Roberts, & Xu, 2011; Howell, 2016c; Jefferson et al., 2006; Miguel Benavente, 2006).

3.5 Augmented CDM Model in Less-developed Countries

Compared to leading industrialized economies, there is limited study purposing adjusting CDM model based on the developing countries background. During a comprehensive change in social, political, legal and economical, the newly industrialized country presents different nature and opportunity which will not show in the stable environment of advanced market economies. Three critical but omitted dimension in developing economies, like in China, they are foreign investment and technology, policy environment and reform, external and spatial economies (Howell, 2016c).

For foreign investment and technology, the spillover effects of FDI will benefit innovation in the host country (Cheung & Ping, 2004). In another word, the intentional and unintentional introduction of technology will arise by transfer capital, knowledge and skilled labor (Gorg & Strobl, 2001). In addition, FDI and its intensity are both positively associated with innovation capabilities. However, the effect's strength relies on the regional absorbing abilities (Fu, 2008). In emerging economies, supports from the public sector is also an essential dimension. The public policies, such as subsidies, are likely to affect all three stages of innovation, from R&D investment to productivity, by altering the firm's overall performances and market environment (Howell, 2016c).

From the region development perspective, China posses unique geographic pattern in industrialization different from other countries, leading to "miracle" rapid industrialization in the past three decades. In China, an economic development zone is a group of policies designed to form an industrial cluster and implement policy experiment, including encouraging innovation or startup and attracting foreign direct investment. It plays an experimental character for future policy design and nationwide extension. Till 2005, central and local governments have created more than 100 clusters across 60 cities since the mid-1980s (Lu & Tao, 2009). In addition to economic/developing zones, rural counties in China, which specialized in specific process or product, are also agglomerated in industrialized clusters. The empirical evidence of cluster-based rural industrialization reveals that the resulting agglomeration helped to reduce technological barriers to entry, promote upgrading production quality, and enhance productivity (Fleisher, Hu, McGuire, & Zhang, 2010).

SECTION 4 MODEL

The empirical model in this research originated from the work of Crépon et al. (1998), henceforth CDM. The original CDM model is formalized in four equations: (1) the firm's decision in invest in R&D activities; (2) the intensity of R&D investment for firm's which has made decision; (3) knowledge production function to measure how much knowledge output is generated from R&D investment; (4) the output production, link the knowledge as input to the firm's labor productivity. The CDM framework has been introduced to empirical research on innovation and productivity with firm-level data over 40 countries (Lööf, Mairesse, & Mohnen, 2017). These applied works extended the original model in many aspects, including econometric methods, data selection and so forth. However, three certain stages are necessary for these researches: (1) firm decided whether and how much effort in R&D; (2) knowledge output is the result of innovation investment; (3) firm's economic performance will be affected by knowledge output.

In contrast to the original CDM model, the augmented model in this research is extended regarding proxy selection, equation extension, and econometric methods choice. For proxy selection and equation extension, the first extension adds an equation of sales by new products (or produced by the new process) into the innovation stage for its unique advantages to estimate firm applicative competence. The second is taking TFP instead of labor productivity to measure a firm's economic performance more comprehensively. For econometric methods choice, Tobit model is applied to R&D investment intensity and innovation outcome intensity. Additionally, the logit model is used due to the binary feature of R&D decision and new patent application. What is more, the random effect model with panel data helps to capture more dynamic information, instead of the static model with cross-sectional data in the original CDM model.

In addition, according to Griffith et al. (2006), most of the firms may make some kinds of effort in innovation, however not all of them will be reported or observable as knowledge outputs. Thus, all firms should be estimated in the CDM model; not just includes the firms have an investment in innovation.

4.1 Stage 1: R&D Investment

The first stage estimates the firm's R&D investment willingness and effort. The R&D intensity is only calculated for the firms which have decided to invest in R&D. Equation (1) models the decision process which causes the firms to launch innovation activities. In the next step, Equation (2) models how much effort the firms invest in innovation.

Therefore, Equation (1) can be expressed as:

$$RD_{i,t} = \begin{cases} 1 \ \ if \ \ RD_{i,t}^{*} = \alpha^{(1)} Support_{i,t}^{(1)} + \beta^{(1)} X_{i,t-1}^{(1)} + \theta_{i}^{(1)} + \epsilon_{i,t}^{(1)} \geq \bar{c} \\ 0 \ \ if \ \ RD_{i,t}^{*} = \alpha^{(1)} Support_{i,t}^{(1)} + \beta^{(1)} X_{i,t-1}^{(1)} + \theta_{i}^{(1)} + \epsilon_{i,t}^{(1)} < \bar{c} \end{cases} \quad (1)$$

In Equation (1), $RD_{i,t}$ is the dependent variable which equals to 1 if firms decide to invest in any R&D activities, and 0 otherwise. $RD_{i,t}^{*}$ is a latent indicator if it is above given threshold $\bar{c}$, through which the firm will plow into R&D expenditure. $Support_{i,t}^{(1)}$ is a vector of five proxies reflecting the strength of government support, with $\alpha^{(1)}$ as the corresponding parameter. It consists of three variables presenting subsidies level and two variables indicating public R&D level.

$X_{i,t-1}^{(1)}$ is a vector of control variables for firm and industry, with $\beta^{(1)}$ as the corresponding parameters. Firm control variables include the firm's age, size, ownership dummies, sales growth rate (with one-year lag), and fixed/intangible capital intensity. Industry control variables are the industry growth rate and subnational region dummies. The industry growth rate (with one-year lag), measured by the ratio of industry sales increase to provincial total sales at giving $t-1$ year, reflects the life cycle effects of one industry. The subnational region dummies are defined by the geographic region of China. Year dummies and province dummies are also included in $X_{i,t-1}^{(1)}$. These dummies are able to capture unobserved policies and social effect. $\theta_i^{(1)}$ gather all unobserved heterogeneity between firms. While $\epsilon_{i,t}^{(1)}$ is the error term.

Due to the binary attributes of the dependent variable and the panel structure of data, a random effect Logit model is the proper choice to estimate Equation (1). The random effect Logit model is helpful to deal with some other time-invariant unobserved heterogeneity, like management skill and regional specific effects. By contrast, the fixed effect Logit model is not able to estimate the effect of time-invariant variables, since all these effects will be captured by fixed effects. Thus, in this research, the random effect is more appropriate than the fixed effect model.

Rho statistics will be reported for each equation to compare the random effect model and panel model, representing the fraction of variance due to the individual effect. Rho>0 indicates that the panel estimator is different from the pooled estimator. In addition, for the Logit model, correct prediction rate will also be reported to express the fitness of model to original data.

Equation (2), the firm's R&D intensity function, can be expressed as:

$$RDI_{i,t} = \begin{cases} \alpha^{(2)}Support_{i,t-1}^{(2)} + \beta^{(2)}X_{i,t-1}^{(2)} + \theta_i^{(2)} + \epsilon_{i,t}^{(2)} & if\ RDI_{i,t}^{*} > 0 \\ 0 & if\ RDI_{i,t}^{*} = 0 \end{cases} \qquad (2)$$

Where $RDI_{i,t}$ is the ratio of a firm's R&D expenditure to its total sales, and $RDI_{i,t}^{*}$ is the latent variable describing the potential effort the firm would like to spend. The state support vector $Support_{i,t-1}^{(2)}$ and firm/industry performance vector $X_{i,t-1}^{(2)}$ keep the same as the same explanation from Equation (1), along with parameter $\alpha^{(2)}$ and $\beta^{(2)}$.

Tobit model also called the censored regression model, is used to estimated Equation (2), due to the non-negative continuous feature and excess zero of the dependent variable. The threshold of left censoring in the model is zero. In addition, random effects will be selected to keep consistent with the previous equation. The poorly performance of the maximum likelihood estimator in the Tobit model with fixed effects is another reason for choosing random effect Tobit model (Honoré, 1993). Rho statistic will also be reported.

4.2 Stage 2: Innovation

The second stage connects the firm's R&D investment with innovation output. Therefore Equation (3) and Equation (4) are the knowledge production functions with different types of innovation output.

Equation (3), modeling for firm's new applied invention patents, can be expressed as:

$$Patents_{i,t} = \begin{cases} 1 \ \ if\ Patents_{i,t} = \gamma^{(3)} RDI^{*}_{i,t-1} + \alpha^{(3)} Support^{(3)}_{i,t-1} + \beta^{(3)} X^{(3)}_{i,t-1} + \theta^{(3)}_{i} + \epsilon^{(3)}_{i,t} \geq \bar{c} \\ 0 \ \ if Patents_{i,t} = \gamma^{(3)} RDI^{*}_{i,t-1} + \alpha^{(3)} Support^{(3)}_{i,t-1} + \beta^{(3)} X^{(3)}_{i,t-1} + \theta^{(3)}_{i} + \epsilon^{(3)}_{i,t} < \bar{c} \end{cases} \quad (3)$$

Where $Patents_{i,t}$ is a binary variable, which equals to 1 if firms applied new invention-patents in the t year, and 0 otherwise. $RDI^{*}_{i,t-1}$ is a latent variable, which is a predicted value of R&D investment intensity from Equation (2) with one time period lag. The one time-period (year) lag allows that firms have time to build prototypes and convert R&D input to innovation achievement. The rest variables and corresponding parameters have the same interpretation as previous equations. Due to the binary feature of $Patents_{i,t}$, and to keep consistent with Stage 1, Equation (3) is estimated by the random effect Logit model.

Equation (4) is expressed as:

$$Innov_{i,t} = \begin{cases} \gamma^{(4)} RDI^{*}_{i,t-1} + \alpha^{(4)} Support^{(4)}_{i,t-1} + \beta^{(4)} X^{(4)}_{i,t-1} + \theta^{(4)}_{i} + \epsilon^{(4)}_{i,t} & if\ Innov^{*}_{i,t} > 0 \\ 0 & if\ Innov^{*}_{i,t} = 0 \end{cases} \quad (4)$$

Where $Innov_{i,t}$ is a continuous variable calculated as the ratio of new products/process sales to the firm's total sales, presenting the firm's innovation intensity.

The other variables and parameters keep the same explanation as above. In estimating Equation (4), according to Equation (1) and (2), a random effect is utilized and the Tobit model is selected based on the non-zero continuous attributes of $Innov_{i,t}$.

4.3 Stage 3: Firm's Productivity

In the final stage, production functions link firm innovation output to its productivity. Two equations are included in this stage. Equation (5) and (6) includes the predicted values of two kinds of innovation outcomes from the previous stages. For Equation (6), the predicted probability of investing in R&D from the first stage is also added to the equation. Thus, Equation (5) and (6) express as:

$$TFP_{i,t} = \gamma^{(5)} Patents^{*}_{i,t-1} + \delta^{(5)} Innov^{*}_{i,t-1} + \alpha^{(5)} Support^{(5)}_{i,t-1} + \beta^{(5)} X^{(5)}_{i,t-1} + \theta^{(5)}_{i} + \epsilon^{(5)}_{i,t} \quad (5)$$

$$TFP_{i,t} = \mu^{(6)} RD^{*}_{i,t-1} + \gamma^{(6)} Patents^{*}_{i,t-1} + \delta^{(6)} Innov^{*}_{i,t-1} + \alpha^{(6)} Support^{(6)}_{i,t-1} + \beta^{(6)} X^{(6)}_{i,t-1} + \theta^{(6)}_{i} + \epsilon^{(6)}_{i,t} \quad (6)$$

Where $TFP_{i,t}$ is the firm's TFP, estimated by the generalized method of moments (GMM). $Patents^{*}_{i,t-1}$ and $Innov^{*}_{i,t-1}$ are the innovation outputs predicted in Equation (3) and (4) with one time period lag. $RD^{*}_{i,t-1}$ is the predicted probability of R&D investment decision with a one-year lag, calculated from Equation (1). The rest of the variables keep the same explanation as previous equations. A random effect model is used to estimated Equation (5) and (6). Rho statistics are used to report the difference of the random effect model and pooled OLS model.

SECTION 5 DATA AND KEY VARIABLES

This section can be separated into four parts. First, I will present the data sources of empirical analysis in Section 5.1. Second, the reasons of I chose dependent variables in this paper instead of the original CDM model will be discussed in Section 5.2. Table 4 lists the summary statistics of dependent variables. Third, the explanation and variable selection of public policy supports are represented in Section 5.3. Finally, Section 5.4 provides variable selections and summary statistics of firms and industry control variables. Table 7 and Table 8 show the summary statistics of the continuous and categorical firm and industry control variables. At the end of Section 5, Table 9 express the definition and data sources of each variable.

5.1 Data Resource

This thesis utilizes the Annual Report of Industrial Firms (ASIF) data compiled by the State Statistical Bureau of China for the 2003-2007 period. The ASIF data consists of all state-owned, privately-owned, and foreign-owned firms with annual sales of at least five million RMB. The ASIF firms produced more than 90% of industrial output and more than 95% of exports in China (Brandt, Van Biesebroeck, & Zhang, 2012). The ASIF data include the majority information of production and sales for each company such as total sales revenue, R&D expenditure, sales revenue from new product and new processes, the number of employees, years of establishment, firm location, and so on.

In additional to ASIF data, this thesis also uses other data including the patent database from the State Intellectual Property Office (SIPO), the Annual Report of Agricultural Technology Statistics (ATS) and the Statistic on China Agricultural Mechanization (SCAM). Such data sources will be discussed by presenting the corresponding variables in Section 5.2 to Section 5.3.

The national industry classification changed four times (1984, 2002, 2011 and 2017) in the past three decades. The agricultural machinery industry in this paper only consists of companies with the first three-digit industry code being “367,” based on the 2003 industry classification. The unique numerical firm IDs along with other information, like address and company name, are used to construct a panel data set. The firm ID may change due to mergers and acquisitions. Under these circumstances, other firm information was utilized to identify a company. On average, from 2003 to 2007, about 95.9 percent of year-to-year matching was solely based on the unique firm IDs, and the other 4.1 percent employed the additional firm information (Howell, 2016b).

Based on the ASIF data, the following key variables were created: 1) R&D investment measured by both investment decision as well as share of expenditure to its total sales revenue; 2) financial support to firms received from central and/or local government; 3) firm’s innovation intensity measured by the ratio of new product and process sales to total firm sales; 4) firm productivity measured by total factor productivity that is constructed based on detailed production information at the firm level. ASIF also provides basic information such as firm size, number of employees, industry, firm location, and years of establishment. The definition of each variable is listed in Table 9 at the end of Section 5.

5.2 Dependent Variables

Five dependent variables are used in the three stages of the structural CDM model. The dependent variables in the first stage indicate whether a firm had any investment in R&D or not and R&D intensity calculated by the total R&D investment divided by the total sales revenue. In the second stage, the firm's innovation outcomes are measured by whether a firm applied any patent and the ratio of sales by new products or processes to total sales. The dependent variable in the third stage was the firm-level total factor productivity (TFP) that was estimated by the generalized method of moments (GMM).

In contrast to the original CDM model, where the accumulated number of patents is used to represent innovation outputs, this study uses both the share of sales by new products or products with new processes and the patent applications to measure firm innovation. Firm patents are widely used in previous CDM studies. There are several shortcomings and disadvantages in using patents to measure firm innovation. First, very few firms have their own patents. Most firms get a free ride on or benefit from the improved knowledge and just imitate successful products in the market, especially when the protection of intellectual property rights is weak. Therefore, firms have less incentive to apply for patents. Second, not all innovation advances are patentable, nor every advance can meet the high criteria of the State Intellectual Property Office (SIPO). New products/process sales may capture part of innovation that is not patentable. In addition, Kleinknecht (2000) points out that the sales ratio of new products is a more robust measure for innovation as it measures not only the amount of both internal and external knowledge achievement but also the ability to apply and convert innovation into product processing and sales. From the explanation and definition from the National Bureau of Statistics of China (2012), new products and processes are expected to have significant improvements in technology, design, or processing in a company. It is worth mentioning that products or process which is new to the firm is not necessarily new to the market.

Patent application data for each firm was collected from the patent database of the State Intellectual Property Office (SIPO) and merged to the Annual Statistics of Industrial Firms (ASIF) data by an algorithm developed by Dr. Anthony Howell and his colleagues at Peking University (Howell, 2016a). According to the matching procedure, 55 percent of patents in SIPO database can be matched to firms in the ASIF dataset. This thesis focuses on only newly applied invention patents since invention patents are deeper than utility model patents regarding novelty. Because it takes a long time, approximately 36 months, to get an invention patent approved, we use the newly applied patents in each year for every company.

The most common measurements of firm's productivity are labor productivity and capital productivity. The two measurements have their own drawbacks. Labor productivity, the intensity of labor-effort, is merely the ratio of the firm's total output to labor input use. It does not include capital intensity, non-capital effort, or technical changes. In the same way, capital productivity is just the ratio of the firm's output to physical capital inputs. TFP takes multiple inputs, including capital, energy, labor, and material, into consideration. It also measures the part of productivity that cannot be explained by labor, physical capital or material inputs. This thesis uses TFP to measure firm productivity and performance. Various estimation approaches are employed to estimate TFP in the literature. In general, generalized method of moments (GMM) offers advantages of solving the correlation of error term over time (Arellano & Bond, 1991; Arellano & Bover, 1995), providing better estimation than the three-step semi-parametric approach developed by Olley and Pakes (1992). Therefore, this thesis uses total factor productivity estimated by GMM.

The summary statistics of dependent variables are shown in Table 4. From 2005 to 2007, 13.39 percent companies decided to invest in R&D, while average R&D investment intensity is 0.2 percent. Only 2.72 percent of companies have at least one patent, an average number of patents applied is 0.097 every year. The average ratio of new products/process sales to total sales is 3.8%. The average total factor productivity is 9.909 for the agro-machinery industry from 2005 to 2007.

Table 4 *Summary statistics of the dependent variables from 2005 to 2007 (pooled)*

Continuous Variables	**Mean**	**Std. Dev.**
R&D investment intensity (%)	0.002	0.028
The share of sales by new products/process (%)	0.038	0.158
Number of patents applied	0.097	0.980
Total factor productivity	9.909	1.736

Binary Variable	**Percentage**
R&D investment decision (1/0)	13.39%
Having at least one patent or not (1/0)	2.72%
Receive production-based subsidy or not (1/0)	8.47%

Source: Calculated by Author from ASIF data

5.3 Policy Variables

The Chinese government provided strong policy supports to boost the national economy and accelerate industrial upgrading and transforming. In the manufacturing industry, the central and provincial governments not only provided significant investments in infrastructures like railway, highway, or harbor but also invested in both public and private research and innovation. Compared to other manufacturing industries, the agriculture sector stagnated for being less efficient and poorly developed, for a long time. The Chinese government employed specific policies for all agriculture-related manufacturing industries, such as pesticide, fertilizer and agricultural machinery. To capture the policy support for the agricultural machinery industry, this thesis incorporates the following three groups of policy variables: purchase subsidies to farmers, production subsidies to agricultural machinery companies, and public agricultural R&D investment.

5.3.1 Purchasing Subsidies for Farmers

The Chinese government started to offer financial subsidies to support farmers in purchasing agricultural machinery in 1998. From 1998 to 2003, the purchasing subsidies were restricted at a low amount and evenly distributed into major grain producing areas in provinces including Heilongjiang, Jilin, Liaoning, Shandong, Henan, Inner Mongolia and Xinjiang (Li, 2008). The policy was gradually adopted in 13 provinces (Li, 2008). In 2004, "Law on Promotion of Agricultural Mechanization," which clearly outlines arrangement and allowance for purchasing subsidies, was released (the NPC Standing Committee, 2004). The law significantly boosted the amount of purchasing subsidies and expanded the policy to every province in following years. This thesis considers purchasing subsidies at both the national and provincial level. Data on purchasing subsidies were from Agricultural Mechanization Statistic, which is jointly compiled by Department of Farm Mechanization (MOA) and Research Center of China Agricultural Mechanization Development (CAU) (2016).

Purchasing subsidy provided farmers, collectives, and agricultural service organizations significant incentives to purchase agriculture machinery. The purchase subsidy variables from the central and provincial government are created separately by provinces each year. The purchase subsidy variable in one province each year is even for every company in the same province. The following table shows that from 2005 to 2007, purchase subsidy from central government double or triple each year from 311.9 million CNY to 2.016 billion CNY. The purchase subsidy from provincial finance grows at a moderate speed, rising from 985.37 million to 1.345 billion CNY. The allocation of purchase subsidy is uneven among provinces. For purchase subsidy from central finance, it paid more attention to major grain-producing provinces, such as Hebei, Jilin, and Anhui. For purchase subsidy from provincial finance, more economically developed provinces are able to provide more budget on purchase subsidy than less developed provinces.

Table 5 *Purchase subsidies (ten thousand CNY) for machinery buyers from the central and provincial government from 2005 to 2007*

	2005		**2006**		**2007**	
	From central government	From provincial governments	From central government	From provincial governments	From central government	From provincial governments
Beijing	78	2,042	300	2,808	826	5,328
Tianjin	50	2,473	235	2,005	600	2,142
Hebei	1,716	1,736	4,233	2,832	9,239	4,391
Shanxi	626	2,493	1,800	2,267	5,200	2,382
Inner Mongolia	1,675	2,278	4,143	1,750	9,580	3,586
Liaoning	1,350	1,000	2,500	3,888	8,300	4,736
Jilin	2,209	494	3,280	575	21,100	420
Heilongjiang	1,500	20,375	2,500	15,203	8,300	18,811
Shanghai	50	2,641	216	6,577	610	9,992
Jiangsu	1,234	11,192	3,427	13,288	7,700	17,663
Zhejiang	350	12,651	1,300	8,374	4,200	7,975
Anhui	2,508	1,244	3,856	1,331	11,188	1,922
Fujian	-	185	971	138	2,387	312
Jiangxi	1,500	906	3,080	1,228	9,400	1,851

Shandong	1,399	8,193	2,720	5,757	9,435	8,371
Henan	1,430	4,007	2,500	5,999	9,100	7,706
Hubei	2,700	1,700	3,440	2,600	9,000	2,392
Hunan	2,100	882	4,600	1,564	11,780	1,240
Guangdong	315	6,360	1,150	9,068	7,466	6,934
Guangxi	598	1,044	1,797	2,322	5,200	2,568
Hainan	300	320	500	539	1,553	396
Chongqing	600	2,703	1,800	4,180	4,300	2,200
Sichuan	1,964	2,342	3,755	2,969	10,306	7,496
Guizhou	750	1,819	1,800	2,264	5,200	3,810
Yunnan	600	696	1,800	1,880	5,800	799
Tibet	-	-	-	-	-	-
Shaanxi	1,000	2,330	2,220	2,431	6,800	2,376
Gansu	466	702	1,800	1,433	5,100	1,280
Qinghai	300	100	520	569	1,300	375
Ningxia	430	885	728	1,347	1,575	987
Xinjiang	1,390	2,747	2,710	2,411	9,100	4,096
Total	31,187	98,538	65,681	109,597	201,645	134,537

Source: Annual Report of Agricultural Technology Statistics Unit: ten thousand CNY

5.3.2 Government Production Subsidies to Agricultural Machinery Firms

In general, manufacturing firms in China may receive two types of financial subsidies, one pertaining to production and the other related to R&D investment (Howell, 2016b) . Both production and R&D related subsidies are found to have effects on firm innovation production, and performance (Girma, Gong, & Görg, 2008; Görg & Strobl, 2007; Howell, 2016b). This thesis only focuses on the production-focused subsidies to agricultural machinery firms because data on production subsidies are available in our dataset while R&D subsidies are not. The following reasons to prefer using production-based subsidies rather than R&D-based subsidies are provided. First, this thesis examines the effects of public subsidies on not only innovation but also on the firm's economic performance. The R&D based subsidies are highly targeted on R&D activity and relatively small in scale. Therefore, the relationship of R&D subsidies and firm's performance is difficult to measure. Production-based subsidies can increase a firm's possibility to invest in innovation activities by improving a company's economic performance and releasing financial burden. Second, data on government subsidies for firm-level R&D are less likely to be publically available. The public R&D subsidies are only available at the provincial level, or only for listed companies, which inevitably leads to narrow down to a much smaller sample study (Boeing, 2016; Guan & Yam, 2015; Di Guo, Guo, & Jiang, 2016). Summary statistics of production-based subsidy is presented in Table 7. From 2005 to 2007, 8.47 percent of total companies received a production-based subsidy, and average production-based subsidy for all companies is 1659.46 thousand CNY.

5.3.3 Public R&D institutes and R&D expenditures

During the past two decades, China has aggressively ramped up R&D investment in all industries. Public R&D institutions play an essential role in fundamental research and leading technological advancement in industries. Due to the cross-industry nature, agricultural machinery R&D was carried out by a joint effort from different ministries in China, including Ministry of Agriculture (MOA), Ministry of Technology (MOT), and

Ministry of Education (MOE). This thesis includes two variables measuring public R&D investment and capacity, namely, the number of public R&D institutes and public R&D expenditure on agricultural mechanization. The information of these two variables was compiled from the Annual Reports of Agricultural Technology Statistics published by MOT and MOA. The estimated public R&D expenditure is calculated by the weighted national total R&D expenditure based on the ratio of provincial industry sales to national industry sales. I recognize the limitation of using the number of public R&D institutes from Agricultural Technology Statistics, as it only includes MOA related but did not include universities and central government-affiliated R&D companies. These two omitted public R&D institutes take a significant share of R&D in agricultural mechanization.

Figure 5 provides the annual funding value for public institutes of agricultural machinery from 2005 to 2015. In the ten years from 2005 to 2015, the annual funding has increased at amazing speed, almost six times. From 2005 to 2007, the time range in the empirical analysis of this paper, the annual funding rose 50% from 59.5 million in 2005. In addition, Table 6 provides the number of public R&D institutes for agricultural machinery for each province from 2005 to 2007. The total institute's number didn’t change much in three years. The institutes are not evenly distributed over the country. The provinces in NE China (like Liaoning, Heilongjiang) and SE China (such as Sichuan and Yunnan) have more agro-machinery institutes.

Figure 5 *Annual funding of public institutes of agricultural machinery from 2005 to 2015 (million CNY)*

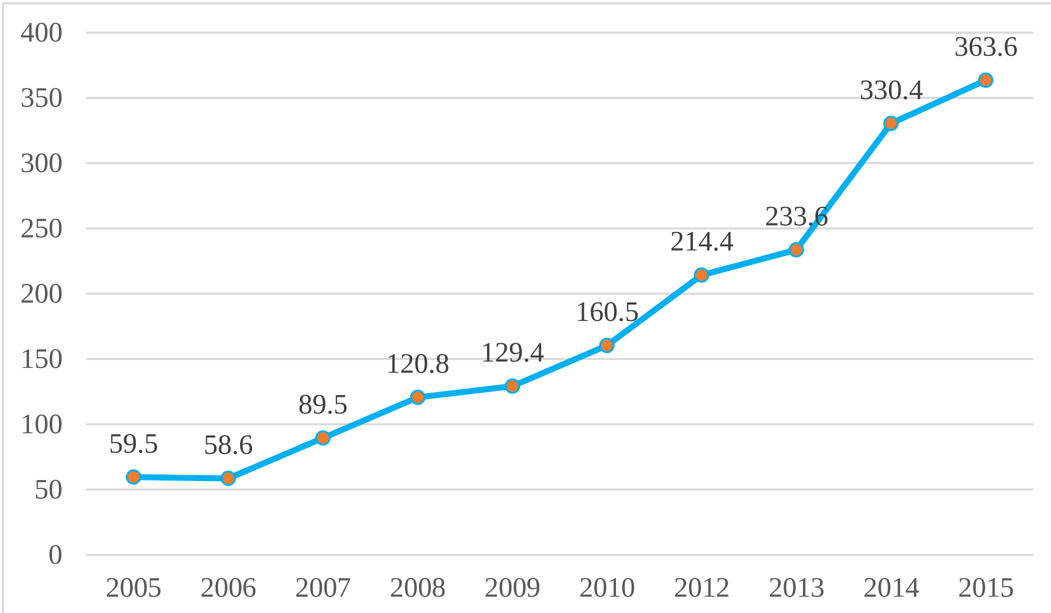


Table 6 *Public R&D institutes for the agro-machinery industry from 2005-2007*

	2005	**2006**	**2007**
Beijing	1	1	1
Tianjin	1	1	1
Hebei	7	6	6
Shanxi	9	9	9
Inner Mongolia	8	7	7
Liaoning	10	11	11
Jilin	7	8	8
Heilongjiang	8	8	8
Shanghai	1	1	1
Jiangsu	3	2	2
Zhejiang	2	2	2
Anhui	7	8	8
Fujian	0	0	0
Jiangxi	3	3	3
Shandong	9	9	9
Henan	3	3	2
Hubei	10	10	10
Hunan	12	11	11
Guangdong	7	5	5

Guangxi	5	5	4
Hainan	1	1	1
Chongqing	1	0	0
Sichuan	11	11	11
Guizhou	8	8	7
Yunnan	15	14	14
Tibet	0	0	0
Shaanxi	6	6	6
Gansu	7	7	7
Qinghai	0	0	0
Ningxia	1	1	1
Xinjiang	4	3	3
Total	167	161	158

Source: Annual Report of Agricultural Technology Statistics

5.4 Firm and Industry Performance Variables

Previous studies with the same data source offered insights in selecting variables (Howell, 2016a, 2016b). Firm control variables need to include basic information to depict the firm's features, like the firm's age, size, sales growth rate, and fixed/intangible capital intensity. In addition, to better distinguish the effect of FDI and state capitals, ownership dummies are created according to the major share of investment sources. What is more, development zone dummies are combined into the dataset to express the influence of policy-oriented industrial agglomeration (Howell, 2016a, 2016b).

Industry control variables are the industry growth rate and subnational region dummies. The industry growth rate is measured by the ratio of industry sales growth to total provincial sales, reflecting the life cycle effects of one industry. The subnational region dummies are defined by the geographic region of China.

The summary statistics of key continuous firms and industry control variables are presented in Table 7 and the categorical variables in Table 8. Average fixed assets per employee are 781.12 thousand CNY, while average intangible assets per employee are only 49.68 thousand per employee. 100% domestic private owned company is the most common ownership structure, taking 82.96 percent of a total number of companies. What is more, 57.48% of companies concentrated in East China, following by Central China taking 17.35%.

Table 7 *Summary statistics of the continuous firm and industry control variables from 2005 to 2007 (pooled)*

Variable	Mean	Std. Dev.
Firm size measured by the number of employees	244.884	1158.506
Firm age (year)	14.047	15.434
The annual growth rate of firm sales revenue (%)	0.492	3.414
Fixed assets per employee (Ten thousand CNY)	78.112	190.436
Intangible assets per employee (Ten thousand CNY)	4.968	23.261
Production-based subsidy to companies (Ten thousand CNY)	165.95	3776.163

Source: Calculated by Author from ASIF data

Table 8 *Summary statistics of the categorical firm and industry control variables from 2005 to 2007 (pooled)*

Variable	Percentage
Located in the development zone (1/0)	
— National-level development zone (%)	2.01%
— Local-level development zone (%)	8.38%
Ownership type	
— 100% domestic private owned (1/0)	82.96%
— 100% SOE (1/0)	6.00%
— 100% foreign/oversea owned	5.47%

— Joint-venture with private capital being majority share (1/0)	2.60%
— Joint-venture with SEO capital being majority share (1/0)	1.67%
— Joint-venture with foreign/oversea capital being majority share (1/0)	1.30%
Economic regions	
— North China (1/0)	6.31%
— North-East China (1/0)	7.51%
— East China (1/0)	57.48%
— South China (1/0)	5.63%
— Central China (1/0)	17.35%
— South-West China (1/0)	2.94%
— North-West China (1/0)	2.78%

Source: Calculated by Author from ASIF data

In this part, I presented the data resources of empirical analysis and list all dependent and independent variables with summary statistics. The advantages and disadvantages of dependent variables I chose in this research instead of the original CDM model have also been discussed. In addition, the reasons why I prefer the above proxies of public support and public R&D have also been addressed in Section 5. In the end, the definition and data sources for each variable are listed in Table 9.

Table 9 *Variable Names and Definitions*

Variable name	Data sources	Descriptions
Firm R&D investment decision	ASIF	1 if firm invests in R&D in year t, and 0 otherwise.
Firm R&D intensity (%)	ASIF	The ratio of R&D expenditure to total sales
Number of patents applied	SIPO	Number of newly applied patent
Having at least one new patent or not	SIPO	1 if the firm applied for invention patent in year t, and 0 otherwise
The share of sales by new products/process (%)	ASIF	The ratio of new products/process sales to total sales
Total factor productivity	ASIF	Companies total factor productivity calculated by the GMM method
Receive production-based subsidy or not	ASIF	1 if the firm received production-based subsidies, 0 not

Purchase subsidy from central government (10 thousand CNY)	SCAM	The purchasing subsidy from central government by province by year
Purchase subsidy from local government (10 thousand CNY)	SCAM	The purchasing subsidy from the provincial government by province by year
Public R&D institutes	ATS	Number of public R&D institution for agricultural mechanization by province
Annual funding for R&D institutes	ATS	weighted yearly total public R&D expenditure by share of provincial industry sales to nationwide total sales
Firm size (employee number)	ASIF	Number of employees in one company
Firm size squared	ASIF	Squared of firm size
Firm age (year)	ASIF	The age of firm measured by year
Firm age squared	ASIF	Squared of firm's age
The annual growth rate of firm sales revenue (%)	ASIF	Take the difference firm sales at t and t-1, then divided by firm sales at t year
The annual growth rate of industrial sales revenue (%)	ASIF	Take the difference of total industry sales in each province at t and t-1, then divided by provincial industry sales at t year
Fixed assets per employee (10 thousand CNY)	ASIF	The ratio of the firm's total fixed assets to employee number
Intangible assets per employee (10 thousand CNY)	ASIF	The ratio of the firm's total intangible assets to employee number
Development zone dummies		
— National-level development zone	ASIF	1 if firm located in national-level developing(economic) zone, 0 not
— Local-level development zone	ASIF	1 if firm located in provincial-level or prefecture-level developing(economic) zone, 0 not
Ownership Structure dummies	ASIF	
— 100% domestic private owned		1 if domestic private investment take 100% share, 0 not (Contrast group)
— 100% SOE		1 if national investment take 100% share, 0 not
— 100% foreign/oversea owned		1 if foreign or overseas (Hongkong/Macao/Taiwan) investment take 100% share, 0 not
— Joint-venture with private capital being the majority share		1 if joint venture which shares of domestic private capital in total investment is the majority, 0 not
— Joint-venture with SEO capital being the majority share		1 if joint venture which shares of the state capital in total investment is the majority, 0 not

— Joint-venture with foreign/oversea capital being the majority share		1 if joint venture which shares of foreign/overseas capital in total investment is the majority, 0 not
Economic region dummies	ASIF	
— North China		1 if province code= 11 to 15, 0 other
— North-East China		1 if province code= 21 to 23, 0 other
— East China		1 if province code= 31 to 37, 0 other
— South China		1 if province code= 41 to 43, 0 other
— Central China		1 if province code= 44 to 46, 0 other
— South-West China		1 if province code= 50 to 54, 0 other
— North-West China		1 if province code= 61 to 65, 0 other
Year dummy	ASIF	1 if the observation is in t year, 0 other
Province dummy	ASIF	1 if the company located in the province, 0 other

Note: ASIF refers to the Annual Report of Industrial Firms

SIPO refers to the State Intellectual Property Office

ATS refers to the Annual Report of Agricultural Technology Statistics

SCAM refers to the Statistic on China Agricultural Mechanization

SECTION 6 EMPIRICAL ANALYSIS

This section presents and discusses the estimation results depicting the relationship between R&D investment, innovation, and productivity at the firm level. I first present the descriptive statistics in Section 6.1. The estimation results for each stage of the CDM structural innovation model are presented in Table 13-15 and discussed in Section 6.2. Section 6.3 discusses key findings along with the study limitations.

6.1 Descriptive Analysis

Descriptive analysis affords an overall glance at the potential association between positive R&D activities, high quantities of innovation outputs, and firm performance. The independent sample t-test is used to compare the means of two groups on the same variables. If the p-value is lower than 0.05, it indicates that there is a significant difference between the means of two groups.

As the literature review in Section 3 shows, companies that make R&D investment and engaged in R&D activities are expected to have better technology, more likely to benefit from innovation, and in return, higher productivity and better economic success.

Table 10 supports the above expectation. Compared with companies which invested nothing in R&D, companies that invested in R&D had a higher probability of having at least one patent application (8.8% vs. 1.8%), a larger average number of patents (0.384 vs.

0.054), and a higher ratio of new product sales in the total sales revenue (11.8% vs. 2.6%). The new products/process sales of R&D investors are even more than twenty times higher than non-investors (46,209 vs. 1,680). Meanwhile, R&D engaged companies tends to have larger firm size (871.55 vs. 148.01), longer firm age (18.95 vs. 13.29), more intensive intangible assets (11.12 vs. 4.02), and higher TFP (10.65 vs. 9.80).

Table 10 *Comparison of companies with and without R&D investment from 2005 to 2007 (pooled)*

	Mean		**t-test**	
	Invest in R&D	Not invest in R&D	t-statistic	p−value
Firm size	871.548	148.010	-12.376	0.000
Firm age	18.952	13.288	-7.161	0.000
Firm sales growth rate	0.649	0.468	-1.026	0.305
Fixed assets intensity	78.432	78.062	-0.038	0.970
Intangible assets intensity	11.120	4.017	-5.945	0.000
Achieve new invention−patents or not	0.088	0.018	-8.409	0.000
Number of new applied invention−patents	0.386	0.054	-6.589	0.000
Sales with new products/process	46208.540	1679.868	-10.411	0.000
The ratio of New products/process sales to total sales (%)	0.118	0.026	-11.484	0.000
Total factor productivity (TFP)	10.650	9.795	-9.673	0.000
Num. of Obs.	3234			

From the literature review of Section 3, R&D investment intensity determines the amount of innovation output; innovation output should then further determine productivity. Table 11 and Table 12 offer some evidence to support this hypothesis. Comparing the companies which have no innovation achievement, TFP of companies which applied new patents is 9.36% higher (10.81 vs.9.88). At the same time, companies with new products sales are 5.27% higher in TFP than their counterparts. In addition, companies with new patents tend to have more new products sales (91,003 vs. 5,310), as well as a higher share of sales with new products (15.2% vs. 3.5%). In the same way, companies with new product sales have a higher probability of applying new patents (6.7% vs. 2.2%) and a larger average number of patents (3.66 vs. 0.06). What is more, Table 11 and 12 both show that companies with innovation outputs turn to have a larger firm size and longer firm's age.

Table 11 *Comparison of companies with and without new invention-patent from 2005 to 2007 (pooled)*

	Mean		**t-test**	
	Achieved invention−patent	Not achieved invention−patent	t-statistic	p−value
Firm size	1,382.668	213.058	-9.468	0.000
Firm age	17.761	13.943	-2.291	0.022
Firm sales growth rate	0.313	0.497	0.499	0.618
Fixed assets intensity	62.613	78.545	0.774	0.439
Intangible assets intensity	8.926	4.857	-1.619	0.106
Ratio of New products/process sales to total sales	0.152	0.035	-6.897	0.000
New products/process sales	91,002.660	5,310.037	-9.547	0.000
Total factor productivity (TFP)	10.809	9.884	-4.949	0.000
Num. of Obs.	3234			

Table 12 *Comparison of companies with and without new products/process sales from 2005 to 2007 (pooled)*

	Mean		**t-test**	
	Have new sales	Not have new sales	t-statistic	p.value
Firm size	609.634	192.814	-6.812	0.000
Firm age	18.228	13.450	-5.850	0.000
Firm sales growth rate	0.466	0.496	0.168	0.867

Fixed assets intensity	66.944	79.706	1.260	0.208
Intangible assets intensity	10.004	4.249	-4.667	0.000
Achieve new invention−patents or not	0.067	0.022	-5.253	0.000
Number of new applied invention patents	0.366	0.060	-5.897	0.000
Total factor productivity (TFP)	10.363	9.844	-5.646	0.000
Num. of Obs.	3234			

6.2 Estimation Results

This part utilizes the three-stage innovation model to further estimate the potential positive causal linkage of innovation inputs, outputs, and productivity. Table 13 includes two equations of Stage 1 (innovation functions), which are firm's decision to invest in R&D activities or not, estimated by a random effect (RE) Logit model, and firm's R&D investment intensity, estimated by a random effect Tobit model. Table 14 shows the results of estimating two equations of Stage 2 (knowledge production function), in which two independent variables were used: the firm's patent, estimated by an RE logit model, and firm's intensity of new product and process (innovation) sales, estimated by an RE Tobit model. Lastly, the firm's TFP (productivity function) of Stage 3 is estimated by a random effect model in Table 15.

Generally, the firm and industry control variables follow the expectation. However, innovation output is not significantly associated with TFP in productivity function, which was not as expected. For firm and industry controls, positive coefficient of firm size with a negative coefficient of its squared term expresses an inverse “U” shape relationship widely on innovation input, output and firm’s productivity. Firm’s age, as the proxy of a company’s operation experience, is consistently insignificant, except in new product and process sales. In addition, ownership dummies have complicated effects in each equation.

For strengths of public support, different approaches show different consequences. The production-based subsidy has consistently positive effects for each equation, whereas, the influence of demand-side policies, like purchase subsidy, is more ambiguous than a supply-side subsidy. What is more, public R&D support plays “complementary” and “substitutes” role in the private R&D expenditure and innovation outputs. The number of institutes have a positive effect on R&D investment and innovation outputs, while oppositely effects on TFP. The government funding for public institutes only has a negative influence on innovation.

6.2.1 The Determinants of R&D Investment

Table 13 presents the result of two R&D equations, one for firms’ decision on R&D investment and another for the intensity of R&D investment. The results of the random effect (RE) Logit model for innovation decision function (Equation 1) are represented as both coefficients and average marginal effects. The marginal effect of RE Tobit model in Equation 2 is average marginal effects of the original dependent variable rather than latent variable. Average marginal effects for continuous variables measure the instantaneous rate of change. For dummy variables, the marginal effects are calculated as the discrete change when dummy change from 0 to 1. Predicted probability of R&D investment is generated from Equation 1 and predicted R&D investment intensity would be generated from Equation 2. These predicted values will be used in the second and third stages.

Rho statistics for Equation 1 and 2 both report significant at 1% level, indicating random effect model works better than the pooled model. In addition, the fixed effect logit model is not able to include time-invariant independent variables. What is more, for the Tobit model, the maximum likelihood estimator (MLE) with fixed effects is biased and inconsistent (Greene, 2004). Thus, the random effect estimator is the more appropriate in this research.

Table 13 *Determinants of R&D Investment*

Dependent Variable (Specification)	Equation (1) **R&D Decision** (RE Logit Model)				Equation (2) **R&D Intensity** (Tobit Model)			
	Coef.		Marginal Effect		Coef.		Marginal Effect	
Production Subsidy Dummy	1.253	***	0.063	***	0.025	***	0.002	***
	(0.320)		(0.016)		(0.008)		(0.001)	
Purchase Subsidy (Central gov)	0.000		0.000		0.000		0.000	
	(0.000)		(0.000)		(0.000)		(0.000)	
Purchase Subsidy (Local gov)	0.000		-0.000		0.000		-0.000	
	(0.000)		(0.000)		(0.000)		(0.000)	
Num. of Ag. Machinery R&D Institutes	0.546		0.027	**	0.004		0.000	
	(0.279)		(0.014)		(0.007)		(0.001)	
Public R&D Expenditure	0.000		0.000		0.000		-0.000	
	(0.000)		(0.000)		(0.000)		(0.000)	
Firm size	0.004	***	0.000	***	0.000	***	0.000	***

	(0.000)		(0.000)		(0.000)		(0.000)	
Firm size squared	-0.000	***	-0.000	***	-0.000	***	-0.000	***
	(0.000)		(0.000)		(0.000)		(0.000)	
Firm age	0.029		0.001		-0.001		-0.000	
	(0.036)		(0.002)		(0.001)		(0.000)	
Firm age squared	0.000		-0.000		0.000	*	0.000	*
	(0.001)		(0.000)		(0.000)		(0.000)	
Firm sales growth rate	0.121	*	0.006	*	-0.002	***	-0.000	***
	(0.066)		(0.003)		(0.000)		(0.000)	
Industry sales growth rate	0.033		0.002		0.009		0.001	
	(0.247)		(0.012)		(0.007)		(0.001)	
Fixed assets intensity	0.000		-0.000		0.000		0.000	
	(0.001)		(0.000)		(0.000)		(0.000)	
Intangible assets intensity	0.011	***	0.001	***	0.000	**	0.000	**
	(0.004)		(0.000)		(0.000)		(0.000)	
Development zone (National-level)	0.921		0.046		0.040	**	0.004	**
	(0.817)		(0.041)		(0.018)		(0.002)	
Development zone (Local-level)	-0.721		-0.036		-0.015		-0.001	
	(0.488)		(0.024)		(0.011)		(0.001)	
Ownership Dummies								
—Pure SOE	-0.888		-0.039	*	-0.007		-0.001	
	(0.560)		(0.022)		(0.012)		(0.001)	
	-0.474		-0.022		-0.023		-0.002	*
—Pure Foreign/Oversea owned	(0.646)		(0.029)		(0.015)		(0.001)	
—Joint-venture (Domestic	-0.644		-0.030		-0.019		-0.002	
private capital majority share)	(0.712)		(0.030)		(0.017)		(0.001)	
—Joint-venture	0.9		0.052		0.013		0.002	
(State capital majority share)	(0.857)		(0.056)		(0.019)		(0.002)	
—Joint-venture (Foreign/	2.15	**	0.146	*	0.032		0.004	
Overseas capital majority share)	(0.934)		(0.077)		(0.020)		(0.003)	
Region								
—North China	2.837		0.268		0.152	***	0.053	
	(2.473)		(0.230)		(0.055)		(0.035)	
—North-East China	-1.365		-0.117		0.024		0.003	
	(3.375)		(0.302)		(0.083)		(0.010)	
—East China	-4.414		-0.291		-0.024		-0.002	
	(3.376)		(0.293)		(0.083)		(0.009)	

—Central China	-3.705	-0.262	-0.005	-0.001
	(3.699)	(0.306)	(0.092)	(0.010)
—South-West China	-3.512	-0.253	0.016	0.002
	(4.446)	(0.340)	(0.111)	(0.013)
—North-West China	0.453	0.042	0.041	0.006
	(2.529)	(0.235)	(0.058)	(0.008)
Time Dummies	Yes		Yes	
Province Dummies	Yes		Yes	
Num. obs.	3215		3234	
Rho	0.730	***	0.499	***
Correct Predicted Rate	88.16%			

Notes: *** p < 0.01, ** p < 0.05, * p < 0.10. The binary dependent variable of Equation (1) equals 1 if the company is engaged in R&D, and 0 otherwise. Margin (1) reports the average marginal effects for the probability of applying new invention-patents from Equation (1). Margin (2) reports the average marginal effects for impact on actual dependent variables. Rho is the percentage of total variance contributed by the panel-level variance component (Rho > 0 indicates that the panel estimator is different from the pooled estimator).

As expected, the production-based subsidies increase both the probability and intensity of R&D investment at 1% significance level. From marginal effect, companies which received production subsidies are 6.3% more likely to participate in R&D than those did not. However, R&D investment intensity of subsidized companies is only 0.2% higher than non-subsidized companies. It indicates that the production subsidy is economically insignificant in terms of encouraging R&D intensity. This result partially conforms to the empirical result of the positive impact of production-based subsidy on a wide range of industries in China (Howell, 2016b). In contrast, the purchase subsidy for farmers, a demand-side policy, has no significant effect on probability and intensity of research, despite the fact that purchase subsidies did help to encourage the demand of agro-machinery and expanding domestic market.

As for public R&D, the marginal effect shows the positive correlation between public institutes number and the probability of R&D investment for firms, while no effect reported on R&D intensity. In fact, companies are 2.7% more likely to invest in R&D, if the province has one more public R&D institutes. Given the frequent public-private research collaboration in the agro-machinery industry, which is discussed in Part 3.1, this finding is not surprising.

In terms of firm characteristics from literature review, firm size is one of the most common and critical factors affecting the propensity of firms to conducted research. As expected, firm size and the squared term are highly correlated with both research propensity decision and research intensity. The positive effects of firm size represent the probability of being involved in research and the intensity of R&D investment increases with firm size. However, the negative effect of squared firm size indicates innovation probability and intensity are a diminishing return. Thus, the relationship between firm size and innovation probability follows an Inverted U-shaped curve, as well as innovation intensity. It is similar to the precedent result of firm-level innovation studies in the pharmaceutical industry of China (Danbo Guo, 2008).

Besides the firm size, other firm controls, such as intangible asset intensity (per employee) also have a positive and significant effect on innovation input. Nevertheless, fixed assets intensity (per employee) shows no sign of significant influences on innovation functions. An intangible asset is an asset which has no physical substance, such as copyrights, trademarks, franchises, and patents. Firm’s intangible assets intensity can represent the intellectual property achieved, the experience of R&D activities and the strategic importance of innovativeness from the past of firm operation. Therefore, the positive effects of intangible assets intensity indicate that the more one company has achieved from past R&D activities and more heavily its strategy emphasizes innovation, the more likely, and intensively it will invest in R&D for the present.

An interesting result is that the firm’s sales growth rate has a positive influence on investment decision, while, inversely on investment intensity, at 1% level significant. It shows that past sales growth will increase the company’s possibility to invest in R&D while decreasing the investment intensity. From the scale of its impact, every 1% increase of the firm’s growth rate will only result in 0.006% increase of R&D investment probability and a neglectable decrease in R&D intensity. As for industry total sales growth, there is no clear evidence to show that the external market environment, such as industry growth rates, will directly lead to different innovation behavior.

The contrast group of ownership dummy is pure domestic private-owned companies. Among the ownership dummies, in R&D decision-making function, the investment probability of joint ventures with foreign/overseas is 14.6% higher than the contrast group, and the probability of pure SOE is 3.9% lower. For R&D investment intensity, the average intensity of pure foreign/oversea owned is slightly lower than the contrast group. These firm’s ownership dummies are derived from the share of investment sources. For instance, for joint ventures with foreign/overseas, the share of foreign or non-China mainland (Hongkong, Macao or Taiwan) capital is the dominant, larger than any resources share. Therefore, it can also be considered as a proxy for FDI strength. It comforts with the previous studies which indicated the same pattern that foreign-funded firms have more innovation competitiveness through "spillover" effects of FDI (Cheung & Ping, 2004; Fu, 2008; Howell, 2016a; Wenqing, 2003).

Development zone dummies and general geographic dummies are used to represent regional effects. In this research, the contrast group of development zone dummies is the companies which are not located in any kind of development zones, and the contrast group of geographic dummies is South China. From equation 2, the average R&D investment intensity is comparatively higher for companies located in the country-level development zone. In addition, the R&D intensity of North China is much higher than in other regions.

6.2.2 The Influence of R&D on Innovation

When we talk about innovation, new products development is not the only variety of innovation activities; in fact, innovation involves a much wider variety of activities, including better quality control methods, as well as new product design and process optimization. To estimate the innovation output, there are two variables introduced to measure innovation. They are whether a company developed its own invention patents or not and the share of new product sales to total sales. The results of RE Logit model for

Equation (3) are represented as both coefficients and average marginal effects. The marginal effect of RE Tobit model in Equation (4) is average marginal effects on the original dependent variable rather than latent variable. Predicted probability of patent possession is generated from Equation (3) and predicted new products sales rate is generated from Equation (4). These predicted values will be used in the third stages.

Table 14 *Effects of R&D, Policy Supports, and firms and industry controls on Firms' Innovation*

Dependent Variable (Specification)	Equation (3) **Have Patents** (RE Logit Model)				Equation (4) **New Products Sales Rate** (Tobit Model)			
	Coef.		Marginal Effect		Coef.		Marginal Effect	
Predicted RD intensity	35.135	***	0.194	**	1.548	**	0.187	**
	(13.130)		(0.082)		(0.685)		(0.083)	
Production Subsidy Dummy	2.224	*	0.012	*	0.224	***	0.027	***
	(1.256)		(0.007)		(0.050)		(0.006)	
Purchase Subsidy (Central gov)	0.000		-0.000		0.000		0.000	
	(0.000)		(0.000)		(0.000)		(0.000)	
Purchase Subsidy (Local gov)	0.000		0.000		0.000	**	0.000	**
	(0.000)		(0.000)		(0.000)		(0.000)	
Num of Ag. Machinery R&D Institutes	0.248		0.001		0.195	***	0.024	***
	(0.229)		(0.001)		(0.044)		(0.005)	
Public R&D Expenditure	-0.001		-0.000		−0.000	**	−0.000	**
	(0.001)		(0.000)		(0.000)		(0.000)	
Firm size	0.003	***	0.000	**	0.000	***	0.000	***
	(0.001)		(0.000)		(0.000)		(0.000)	
Firm size squared	-0.000	**	-0.000	**	-0.000	***	-0.000	***
	(0.000)		(0.000)		(0.000)		(0.000)	
Firm age	-0.049		-0.000		-0.014	**	-0.002	**
	(0.149)		(0.001)		(0.006)		(0.001)	
Firm age squared	0.000		0.000		0.000	**	0.000	**

	(0.003)		(0.000)		(0.000)		(0.000)	
Firm sales growth rate	-0.026		-0.000		-0.013		-0.002	
	(0.109)		(0.001)		(0.010)		(0.001)	
Industry sales growth rate	0.640		0.004		-0.078	*	-0.009	*
	(1.009)		(0.006)		(0.045)		(0.005)	
Fixed assets intensity	-0.009		-0.000		0.000		-0.000	
	(0.008)		(0.000)		(0.000)		(0.000)	
Intangible assets intensity	0.018		0.000		0.001		0.000	
	(0.016)		(0.000)		(0.001)		(0.000)	
Development zone (National-level）	1.593		0.009		0.067		0.008	
	(2.332)		(0.013)		(0.132)		(0.016)	
Development zone (Local-level）	0.000		0.000		-0.171	**	-0.021	**
	(.)		(.)		(0.083)		(0.010)	
Ownership Dummies								
—Pure SOE	2.012		0.011		0.065		0.008	
	(2.205)		(0.013)		(0.080)		(0.011)	
—Pure Foreign/Oversea owned	0.559		0.003		-0.028		-0.003	
	(2.065)		(0.011)		(0.101)		(0.011)	
—Joint-venture (Domestic	-2.841		-0.011		0.092		0.012	
private capital majority share)	(3.027)		(0.009)		(0.097)		(0.014)	
—Joint-venture	11.669	***	0.152	***	0.260	*	0.041	
(State capital majority share)	(2.200)		(0.045)		(0.149)		(0.031)	
—Joint-venture (Foreign/	7.014	**	0.058		0.258	*	0.041	
oversea capital majority share)	(2.769)		(0.043)		(0.148)		(0.031)	
Region								
—North China	-3.349		-0.018		2.208		0.869	
	(2.932)		(0.015)		(90.793)		(10.439)	
—North-East China	-6.452		-0.028	**	0.091		0.007	
	(3.995)		(0.014)		(90.793)		(6.179)	
—East China	-1.021		-0.006		0.807		0.122	
	(1.976)		(0.012)		(90.793)		(8.366)	
—Central China	-0.841		-0.005		0.045		0.003	
	(2.128)		(0.013)		(90.794)		(6.088)	
—South-West China	-4.277		-0.022		-0.762		-0.023	
	(4.045)		(0.017)		(90.795)		(5.442)	
—North-West China	0.000		0.000		1.487		0.384	
	(.)		(.)		(90.793)		(10.034)	

Time Dummies	Yes		Yes	
Province Dummies	No		Yes	
Num. obs.	2360		2360	
Rho	0.969	***	0.728	***
Correct Predicted Rate	71.21%			

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The binary dependent variable of Equation (3) equals 1 if the firm applied new invention-patent this year, and 0 otherwise. Margin (3) reports the average marginal effects for the probability of applying new invention-patents from Equation (3). Margin (4) reports the average marginal effects for impact on actual dependent variables. Rho is the percentage of total variance contributed by the panel-level variance component (Rho > 0 indicates that the panel estimator is different from the pooled estimator).

In this stage, the predicted values of R&D investment intensity from Equation (2) are injected into both Equation (3) and (4) with a one-year lag. It takes "time-to-build" for firms into consideration. The effects of innovation input (R&D intensity) are both statistically and economically significant on both kinds of innovation output in Equation (3) and (4). The marginal effect of Equation (3) reports that the probability of applying new patents will increase 0.194% as 1% increase of innovation inputs. Similarly, every 1% increase in R&D investment intensity will result in 0.187% increase in the share of sales with new products. This result will be further discussed in Section 6.3.1.

In terms of policy encouragement, production-based subsidy plays a positive role in converting innovation investment into knowledge outcome. The marginal effect shows the probability of applying new patents for the subsidized firm is 1.2% higher than firms without subsidy. Similarly, for a share of sales with new products, the subsidized firm is 2.7% higher than non-subsidized firm. In addition, purchase subsidies from the provincial government are beneficial for knowledge production of new products sales, but no effects on patents. However, it seems not economically significant for the effect of purchase subsidy on innovation output.

Besides, public R&D activities display a complicated role. In Equation (4), the number of research institutes is strongly associated with new products sales through "spillover" effect of public R&D. In firm located province, each public R&D institute increase leads to 2.4% growth in share of sales with new products. In comparison, provincial public expenditure in R&D is failed to affect private knowledge production positively. From past study, the substitution effect between public and private R&D investment may be an explanation for this result (David et al., 2000). In another word, strong public R&D expenditure may crowd out private investment and discourage the efficiency of knowledge production.

Keeping consistency with the preceding stage, firm size shows a positive effect on innovation outputs, while its squared term is negative in Equation (3) and (4). Thus, it expresses an inversed-U shaped relationship with patents possession and new products sales rate. By contrast, firm age has a negative effect only on new products sales, as well as its squared term, presenting a U-shaped relationship with innovation output. It indicates that with the company experience increasing, the company may meet choke point in its R&D development especially for new products and process sales rate.

As for the ownership influence aspect, probability of applying new patents for joints venture with state capital is 15.2% higher than the contrast group, which is the pure domestic private owned company. This result follows the pattern from some research about the special relationship between ownership and innovation in China. It will be further discussed in Section 6.3. Additionally, joint ventures with foreign or HMT capital and joints venture with state capital also express significant coefficient in both types of innovation outputs. However, the marginal effects are insignificant.

In terms of regional effects, the probability of applying new patents of companies in North-East China is 2.8% lower than South China. The negative coefficient of local zone dummy shows that companies in the provincial or prefecture-level development zones have weaker abilities to convert R&D inputs to knowledge output.

6.2.3 Estimates for the Effect of Innovation on Firm Productivity

In terms of the third and final stage, Table 15 shows the result of the firm's productivity functions, estimated by random effect regressions. TFP is used to measure the part of production growth that cannot be explained by labor, capital, or other inputs. Equation (5) and Equation (6) both includes the predicted probability of patent possession and the predicted value of new products/process sales rate from Stage 2. In addition, Equation (6) also includes the predicted probability of R&D investment from Stage 1.

Table 15 *Effects of R&D, Innovation, and Public Policies on Firm Productivity*

	Equation (5)	Equation (6)
Dependent Variable	**TFP1**	**TFP2**
(Specification)	(RE Regression)	(RE Regression)

	Coef.		Coef.	
Predicted RD intensity			9.331	***
			(2.025)	
Predicted Patent ownership	-0.009		-0.539	
	(1.477)		(1.474)	
Predicted New Products Sales Rate	0.095		-0.157	
	(0.090)		(0.105)	
Production Subsidy Dummy	0.193	**	0.193	**
	(0.095)		(0.094)	
Purchase Subsidy（Central gov）	0.000	**	0.000	**
	(0.000)		(0.000)	
Purchase Subsidy（Local gov）	0.000		0.000	
	(0.000)		(0.000)	
Num of RD Institutes	-0.089		-0.142	**
	(0.072)		(0.073)	
Public RD Expenditure	0.000		0.000	
	(0.000)		(0.000)	
Firm size	0.001	***	0.000	***
	(0.000)		(0.000)	
Firm size squared	−0.000	***	−0.000	**
	(0.000)		(0.000)	
Firm age	0.011		0.017	
	(0.013)		(0.013)	
Firm age squared	0.000		0.000	
	(0.000)		(0.000)	
Firm sales growth rate	0.010		0.010	*
	(0.006)		(0.006)	
Industry sales growth rate	0.050		0.085	
	(0.062)		(0.062)	
Fixed assets intensity	0.004	***	0.004	***
	(0.000)		(0.000)	
Intangible assets intensity	-0.001		-0.001	
	(0.001)		(0.001)	
Development zone（National−level）	0.253		0.089	
	(0.265)		(0.266)	
Development zone（Local-level）	0.178		0.260	
	(0.161)		(0.161)	
Ownership Dummies				

—Pure SOE	-0.733	***	-0.698	***
	(0.160)		(0.160)	
—Pure Foreign/Oversea owned	0.424	**	0.532	***
	(0.194)		(0.194)	
—Joint-venture	0.273		0.320	
(Domestic private capital majority share)	(0.197)		(0.196)	
—Joint-venture	0.172		0.129	
(Stage capital majority share)	(0.303)		(0.302)	
—Joint-venture	0.544		0.302	
(Foreign/oversea capital majority share)	(0.365)		(0.367)	
Region				
—North China	1.453	*	0.661	
	(0.880)		(0.894)	
—North-East China	1.371		1.954	*
	(1.017)		(1.019)	
—East China	2.887	***	3.775	***
	(0.962)		(0.977)	
—Central China	2.700	**	3.332	***
	(1.088)		(1.091)	
—South-West China	3.239	**	3.666	***
	(1.316)		(1.312)	
—North-West China	1.344		1.468	*
	(0.887)		(0.884)	
Time Dummies	Yes		Yes	
Province Dummies	Yes		Yes	
Num. obs.	1933		1933	
Rho	0.739	***	0.741	***

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Rho is the percentage of total variance contributed by the panel-level variance component (Rho > 0 indicates that the panel estimator is different from the pooled estimator).

The result denies the systemic association between innovation outputs and productivity, which does not exactly follow the expectation from the literature review. It shows that neither of the two innovation outputs (probability of apply patents, and new products sales rate) from Equation 5 and 6 shows a significant relationship with TFP. However, Equation 6 shows that the predicted value of R&D intensity is significantly associated with TFP. Previous studies have provided some insight into possible explanations, including longer time-to-build, neglecting of organizational and marketing innovations, and the complementary effects between different innovations. These possible explanations will be discussed in Section 6.3.

The difference of Equation (5) and (6) are expressed in the effect of private R&D investment decision and public R&D institutes. Equation (5) does not include private R&D investment decision, and there is no sign of the significant relationship between public R&D institutes number and TFP. In comparison, private R&D decision is included in Equation (6). In this situation, private R&D decision shows the significant positive effect on TFP at 1% significance level. Every 1% percent increase in the probability of private R&D investment will result in TFP growth by 0.093. However, the public institute's number is oppositely associated with TFP. Each public institute for agro-machinery research will lead to 0.142 decreases in firm’s TFP. This result indicates that the substitution effect between public and private R&D may exist in the agro-machinery industry. It also indicates there may be other potential channels to converting R&D investment to TFP, more than patents and new products. It will also be further discussed in Section 6.3.

In terms of policy intervention, the positive contribution of product-based subsidy to the firm's productivity is still noticeable in the TFP equation. In both Equation (5) and (6), TFP of subsidized companies is 0.193 higher than non-subsidized companies. This evidence follows the expectation from the literature review. As for demand-side policy, purchase subsidy from central government has encouraged further growth of the firm's productivity.

For firm and industry control, the firm size keeps displaying an inverted-U curve in productivity function. In addition, firm sales growth and fix assets intensity are found to be highly significant variables, offering a positive influence on TFP. This result indicates that firms which have a stronger ability to deploy its fixed assets will have higher average TFP than low capital-intensive companies. The positive relationship between firm sales growth rate and TFP represented that the success of past growth will also encourage present productivity.

In terms of differences in various ownerships, pure foreign ownership, and pure SOE showed to be significant. The average TFP of pure foreign or overseas owned companies markedly exceeds pure domestic private owned, 0.42 higher in Equation (5) and 0.53 higher in Equation (6). As mentioned in the previous stage, the advanced technology will be introduced to industry along with inward FDI. By contrast, the average TFP of pure SOEs is significantly lower than pure domestic private companies by around 0.7.

For regional effects, the development zone dummies express no significant effect on TFP. However, there are significant differences between different geographic regions.

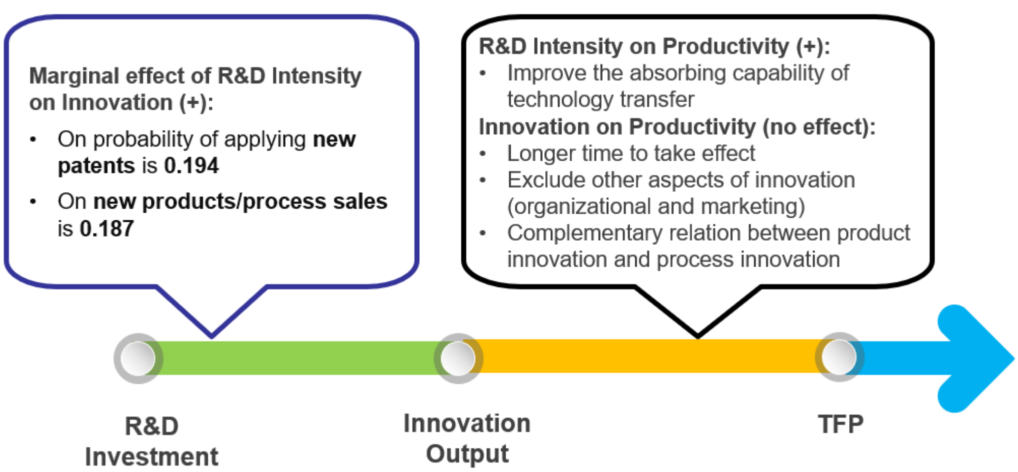
Average TFP of companies in East, Central, and South-West China is much higher than the contrast group in both Equation 5 and 6. Other three regions also show significant positive effects. However, the effects in these regions not consistent in two equations.

6.3 Discussion and Limitation

In this part, I will interpret and describe several important findings from the empirical analysis in Section 6.2. This part connects empirical results, expectations, and past literature. It will also include possible implications in other studies and possible improvements for future research.

6.3.1 The Effects of R&D on Innovation and Productivity

Figure 6 *Summary of R&D investment's effects*



In Section 6.2, the empirical results provide evidence to support the assumption that

R&D investment by firms is strongly associated with innovation outputs. The marginal effect of private R&D intensity on new products sales rate is 0.187. The previous studies in China also provide the effect of R&D on innovation. The elasticity of R&D to innovation in overall Chinese industry is 0.202, while the elasticity on Chinese pharmaceutical industry is higher (0.325) (Danbo Guo, 2008; Jefferson et al., 2006). From the recent paper from Howell (2016b) about Chinese manufacturing industry, he points out that the impact of R&D intensity on innovation investment is higher for high-tech (0.750) and low-tech (0.694) industries and lower for medium-low (0.293) and medium-high (0.277) industries.

Comparing the effect of R&D on innovation among countries, previous studies confirm the differences of effect strength among different countries and different industries. From the research on four European countries, the impact of R&D intensity is lower on process innovation in the UK, and it is higher on product innovation in France (Griffith et al., 2006). Comparing two studies in Spain with the same dataset, the Technological Innovation Panel (PITEC) found the effect of R&D intensity on energy industry innovation is higher than food industry innovation. In addition, R&D intensity shows various levels of influence on different forms of innovation. For instance, Costa-Campi et al. (2014) report that the elasticity of R&D with respect to process innovation is highly elastic (1.497), while the elasticity on products innovation is less elastic (0.395).

As for the effect of R&D on the firm’s productivity, the empirical result in this paper shows a strong association between R&D intensity and TFP in the agricultural machinery industry, conforming to a large literature. For example, Lichtenberg (1992) found that the increase in productivity due to a firm's R&D investment is around six times greater than the return to investment in equipment and structures. What is more, R&D will effect TFP through two channels: encouraging indigenous innovation and increasing the absorptive capacity of technology transfer (Griffith, Redding, & Reenen, 2004). These two channels will be further explained in Section 6.3.2.

6.3.2 The Effect of R&D and Innovation on Productivity

From estimated results, neither of the innovation variables show a significant relationship with TFP in equations (5) and (6). However, Equation 6 shows that the predicted value of R&D intensity is significantly associated with TFP. The following are the possible explanations from previous studies.

First, previous studies point out that R&D has two ways to effect firm's productivity; One is the conventional role of developing innovation, another is promoting absorptive capacity (technology transfer) (Griffith et al., 2004). More R&D will develop the firm's ability to understand and absorb new knowledge, which speeds technology introduction at the firm (Griffith et al., 2003). Other than endogenous innovation, technology transfer is another way to improve productivity. The positive effect of R&D intensity and insignificance of innovation result on TFP indicates that technology introduction may have great influence for agro-machinery industry and it should also be taken into consideration in future research.

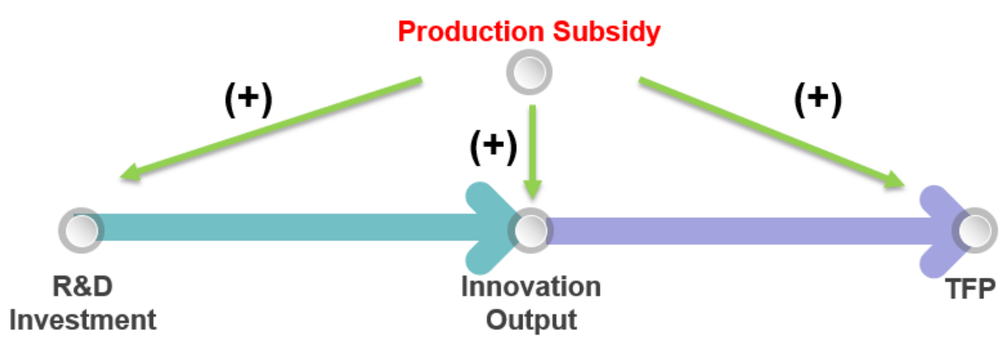
Second, it may take a longer time to show the significant productivity impact after investing R&D resources into a company. Some innovations require substantial time lags to be incorporate them into the production process and increase productivity. Past research indicates that translating new technology into economic significance will happen long after R&D resources and innovation (Sun, 2010). In Huergo and Jaumandreu (2004) research of panel of Spanish firms, process innovation can accur a medium rate three-year-long TFP increase.

Third, innovation is not limited within product or process progress. Organizational innovation or marketing innovation will also result in TFP growth. Polder, Leeuwen, Mohnen, and Raymond (2009) argues that organizational innovation has the strongest effects on productivity and, when combined with organizational innovation, product, and process innovation, shows a positive effect on productivity. Organizational change is also found in productivity growth at the firm-level in a study of UK industries (Crespi, Criscuolo, & Haskel, 2007). However, organizational innovation and marketing innovation are not included in this research due to the data limitation. Thus, it is possible to lead an omitted-variable bias, then drive product innovation insignificance on TFP.

Fourth, Mohnen and Hall (2013) have collected the evidence of complementarity between different forms of innovation in various countries. In aforementioned paper, when both of innovation appear together, the coefficient of product innovation and process innovation turn out non-significant (Griffith et al., 2006; J Mairesse & Robin, 2009; Musolesi & Huiban, 2010). In this research, however, it is not able to separate the effect of product and process innovation. If they are separable, the complementarity can be tested by checking whether it shows higher performance when jointly using two or more innovation variables (Mohnen & Hall, 2013).

6.3.3 Effects of the Production-based Subsidies on Each Stage

Figure 7 *Summary of production subsidies' effects*



In this research, the production-based subsidy, as a proxy of supply-side support from the government, has consistently shown positive effects in each stage of R&D investment, innovation ,and firm productivity. In agro-machinery industry, the subsidized companies are more likely to invest in R&D, have higher R&D investment intensity, achieved more innovation outcomes, and have higher average TFP than unsubsidized companies.

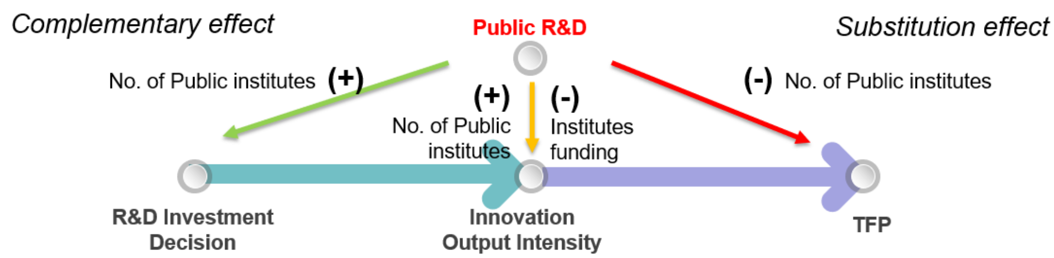
The recent research of Howell (2016b) also focused on the effects of production-based subsidies—the major policies in China's "picking winner" strategy — on innovation process and firm's productivity in overall manufacturing industries. He found that the production-based subsidies can promote firms' R&D expenditures and new products sales; however, this results in a firm's lower efficiency and economic performance. The possible expectation is that, in the "picking winner" strategy, the policymakers are willing to encourage the state-backed firms eventually converting into successful innovators, then generate a large social welfare benefit, at the cost of a lower firm's efficiency. Howell (2016b) further doubted this expectation and found that the TFP gains of subsidized companies are significantly smaller than unsubsidized companies which also become innovators. Comparatively, this thesis reveals that production subsidies of "picking winner" strategy do have positive effects on innovation process as well as firm's efficiency, at least in the agro-machinery industry during the short time period covered.

Other researches of public subsidies mostly focus on the effect of R&D subsidies on private R&D and innovation. Some studies found the positive effects on innovation， in the various countries, including the U.S. (Audretsch et al., 2002), Ireland (Görg & Strobl, 2007), and Germany (Czarnitzki & Hottenrott, 2011).

Comparatively, some studies cast doubt on the positive effects of public subsidies on innovation. The study of Zúñiga-Vicente, Alonso-Borrego, Forcadell, and Galán (2014) mentioned that one-third of the studies on public subsidies shows a crowding out effect or no significant effect. Some studies on China's funding program on R&D express serious skepticism. Brandt and Rawski (2008) and Hu, Liang, Pray, Huang, and Jin (2011) found public agricultural research crowded out private research.

6.3.4 The Role of Public Research

Figure 8 *Summary of public R&D's effects*

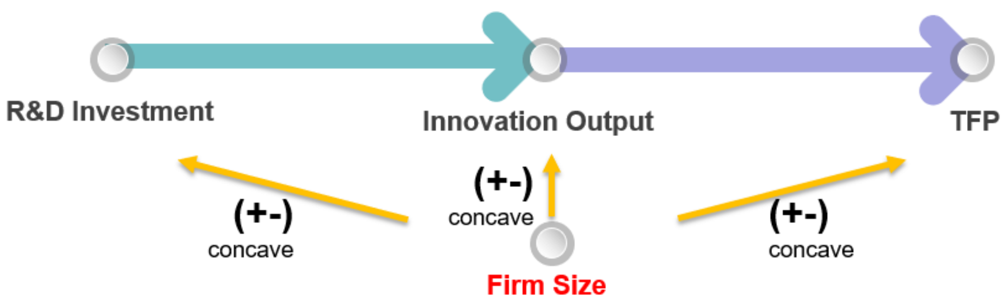


The result of this research indicates both the substitution effect and complementary effect of public R&D. The number of public agricultural machinery research institutes in a province have a positive impact on firms' decisions to conduct research, but the size of public R&D expenditure does not and neither variable affect research intensity. Public research institutes and expenditure have no impact on innovation measured by patents. But research institutes are positively associated with the share of sales from new products in total sales while public expenditure in negatively associated with innovation intensity. When a firm's R&D intensity is controlled, the coefficient of public institutes variable has a negative impact on TFP. This suggests that the impact of public research on TFP is through its positive impact on private R&D and innovation.

The impact of public R&D has a positive effect and plays a complements role on private R&D. This finding is different from the findings in China of Hu et al. (2011) which found crowding out, but is similar to most number of studies finds positive "spillover" effects of public R&D to private R&D (Audretsch et al., 2002; Diez, 2000; Guellec & Van Pottelsberghe De La Potterie, 2003). The opposite effects of public and private R&D in Equation 6 show "crowding out" effects in terms of improving productivity. Bienkowska, Larsen, and Sörlin (2010) point out one explanation that when public institutes occupy some technology niches, it will lead to blocking the transferring knowledge.

6.3.5 Inverted U Relationship of Firm Size on CDM model

Figure 9 *Summary of firm size's effects*



From the empirical analysis, it shows consistent inverted U effect of firm size on R&D investment, innovation output, as well as productivity in agro-machinery industry. The impacts of firm's size measured by the number of employees are diminishing returns.

The past literature also reveals that firm size is one of the key-driven factors affecting the firm's decision on R&D investment as well as its intensity. For example, Shefer and

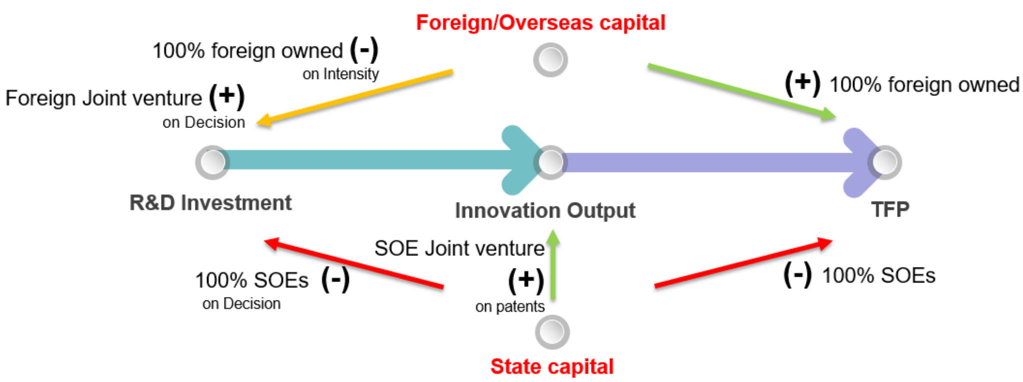
Frenkel (2005) display that large firms are more likely to invest and tend to invest more in R&D than small firms. Moreover, for firm productivity, some studies also find that larger firms tend to be more efficient than small-sized firms (Diaz & Sánchez, 2008; Van Biesebroeck, 2005).

However, the effect of firm size on innovation varies in different industries and countries. Compared with the Chinese agro-machinery industry in this paper, the precedent result of the pharmaceutical industry in China (Danbo Guo, 2008) indicates the similar inverted U-shaped relationship between innovation and firm size. The association between innovation and firm size, however, is U-shaped. In addition, Lööf et al. (2001) compared the impact of firm size on R&D intensity in three Nordic countries and reported a negative effect in Finland, positive effect shows in Norway, while firm size has no significant impact in Sweden. Some studies provide an explanation because technology regime and market structure are different among countries, the effect of firm size on innovation and productivity will not be consistent (Acs & Audretsch, 1987; Revilla & Fernández, 2012).

In addition, empirical studies in various countries show different associations between firm size with innovation input, innovation output or firms' performance. For example, from the original CDM study of Crépon et al. (1998) in France, the possibility of investing in research is expected to increase with firm's size (number of employees), while there is no significant relationship between firm size and research capital intensity.

6.3.6 Ownership and Investment Sources' Impact

Figure 10. *Summary of the effects of foreign/overseas capital and state capital*



Generally, the results of this research indicate that, compared with domestic private companies, the joint-ventures with foreign/overseas (Hongkong, Macao, or Taiwan) are more likely to invest in R&D. The joint-ventures with state-capital have a stronger ability to achieve innovation. While the pure foreign/overseas owned companies have higher TFP, they had less R&D investment intensity. By contrast, pure SOEs are less efficient in TFP and less likely to invest in R&D. In general, the ownership differences via the capital share from different sources have complicated effects on R&D, innovation, and productivity. The technology spillover from foreign direct investment (FDI) and SOEs reform are two hidden driving factors regarding the above result.

For the technology "spillover" via FDI, previous studies about Chinese industry indicated that foreign-funded firms have more innovation competitiveness and higher productivity through "spillover" effects, such as reverse engineering, skilled labor turnover, and so forth (Cheung & Ping, 2004; Fu, 2008; Howell, 2016a; Wenqing, 2003). The spillover effect happens not only in transitioning economies but also in well-developed countries. For instance, the work of Branstetter (2006) points out that knowledge spillovers in the U.S. happened both outward investment to Japanese firms and inward investment from Japanese firms.

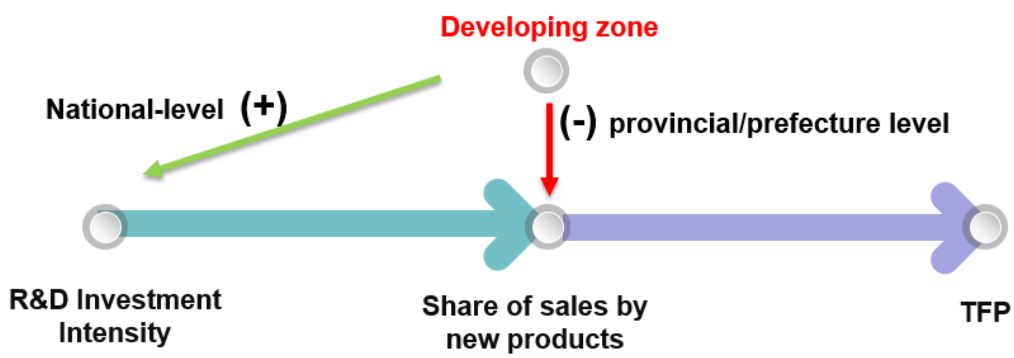
In addition to the "spillover" effect, to get the domestic marketing strategy support, technology transfer is likely to be the return to achieve better multinational cooperation. Therefore, foreign joint-ventures in China are likely to have R&D investment, given the technical support from foreign and overseas. By comparison, for pure foreign/overseas owned companies, multinational corporations carry out most of the researches at home countries. In addition, the level of intellectual property rights protection strongly determines FDI strength than many other policies for some countries (Seyoum, 1996). Awokuse and Yin (2010) also found the positive effects of the strength of intellectual property rights on the surge in FDI in China. Therefore, due to a low level of intellectual property rights, the foreign-owned companies have lower R&D investment intensity during the time-period of this paper. TFP of foreign-owned companies is still higher than domestic private companies through the spillover effect.

In terms of the SOE reform, it is a series of policies designed to rejuvenate traditional SOEs, beginning with decentralization, introducing market competition, and remastering the managerial and incentive systems from the 1980s (Zhang, Zhang, & Zhao, 2001).Its further policies aim to improve the performance of medium or large SOEs, through encouraging emerging and acquisition, converting to joint stock companies, and laying off redundant labors (Zhu, 1999). The combination of state and nonstate capital in various ownership type can represent the underlying process of SOE reform (Jefferson, Albert, Guan, & Yu, 2003). The share of state assets reflects the assets structure of SOEs. Jefferson et al. (2003) reveal that state-owned joint-ventures have higher R&D outcomes than wholly SOEs and domestic private companies, while wholly SOE has the lowest efficiency (TFP), as well as efficiency growth than companies of other ownership types, from 1995 to 1999. The empirical result of agro-machinery industry in this paper conforms to the above findings. State-owned joint ventures can be considered as the pioneers in SOE reform and achieved more innovation outcomes. In contrast, wholly SOEs are lagger in SOE reform, less likely to invest in R&D, and have lower TFP than domestic private companies.

As a result, to further encourage R&D investment and innovation, improve firm-level TFP, policymakers need to focus on intellectual property rights, FDI encouragement policies, and further SOE reform.

6.3.7 Development Zone's Impact

Figure 11 *Summary of Development zone's effects*



Companies in national-level zones tend to invest in R&D more intensively, while companies in local-level zones show weakness in converting R&D investment into innovation outputs, compared with companies which are not in any zone. It indicates that, opposite to the expectation, policies in provincial/prefecture level development zones perform negative influences on innovation for the ago-machinery industry.

Although development zones are widely implemented at all levels, it turns out to be not as successful as policymakers expected, especially for provincial or prefecture-level zones. X. Wang and Cui (2003) found that the size of urban development zone in China is larger than foreign counterparts, while it is much lower in terms of average returns. This "Development Zone Fever" started from the success of pilot programs in Shanghai and Shenzhen at the late 1970s, the beginning of "opening up" policy. Till 2005, central and local governments have created more than 100 clusters across 60 cities since the mid-1980s (Lu & Tao, 2009). "Development zone fever" combined with lagging administrative reforms, leads to wasteful development, social unrest, and heavy local governments' debts (Wei, 2015).

Policies of provincial/prefecture development zones need to be redesigned in the future in the guides of efficient resources allocation, extra start-up encouragement, convenient R&D collaboration, and better industrial service system.

In conclusion, Section 6 presents and discusses the effects of public policies on agro-machinery companies and the relationship between R&D investment, innovation, and productivity. The descriptive statistics are listed in Section 6.1. The estimation results for the innovation model are presented and explained in Section 6.2. Then, Section 6.3 further interprets and discusses the key findings of the empirical analysis, present the possible directions in future policies design, and fill in existing gaps in previous researches.

SECTION 7 CONCLUSIONS AND POLICY IMPLICATIONS

This paper investigates the key drivers of R&D and innovation, then how R&D innovation affects productivity based on firm-level data in the agricultural machinery industry from the ASIF and other annual reports in China. I estimate a structural model that links R&D investment, innovation outputs and firm productivity. The model is in the tradition established by Griliches (1979), of a type often referred to as CDM models (Crépon et al., 1998). The following conclusions are drawn from the empirical analysis of this research.

First, the determinants are remarkably similar in the R&D investment decision and the investment intensity; the determinants consist of production subsidies, firm size, firm sales growth rate, intangible assets, and type of ownership. Unsurprisingly, R&D investment is strongly associated with innovation outputs. The marginal effect of R&D intensity on the probability of applying for new patents is 0.194; marginal effect of the share of sales with new products/process with respect to R&D intensity is 0.187. However, innovation outputs show no significant influence on a firm's productivity. The explanation of this result, including the role of R&D in promoting technology transfer, perhaps lies in the long-time lag between filing for patents and actual use of the new innovations in actual production, and perhaps also in the omission of organizational and marketing innovation measures from the analysis, and neglected possible complementarity between innovation forms.

Second, in terms of public support, different policies show diverse effects. The production-based subsidy has consistently positive influences on R&D investment, innovation outputs, and firm productivity. By contrast, the influence of subsidies for farmers to purchase machinery is inconsistent. Purchase subsidy from local government has positive effects on new products sales rate, while purchase subsidy from central government is positively associated with TFP. What is more, public R&D plays both “complementary” and “substitute” role. The companies located in provinces with more public R&D institutes are willing to invest in R&D and tend to have a higher share of sales by new products/processes, however, lower total factor productivity. As for annual fundings to public institutes, it shows negative effects on private innovation.

Third, firm attributes also indicate factors seemingly vital to innovation production and firm productivity. The relationships between firm size and innovation investment, innovation outputs and productivity are inverted U-shaped consistently. I also find that the firm’s ownership, estimated by shares of capital sources, plays an important role in R&D, innovation, and productivity, in which the SOE reforms and spillover effect via FDI are driven factors. Compared to other types of ownership, joint-venture with foreign/oversea capital has a higher probability to invest in R&D, and more innovation outputs, state capital dominated joint-ventures has more innovation outcomes, pure SOEs are lower in TFP, and pure Foreign/Oversea owned companies are higher in TFP. Furthermore, the firms with higher intangible assets per employee are more likely to engage in R&D activities. Similarly, the firms with higher fixed assets per employee tend to have higher TFP.

All these empirical results offer potential insights into improving the productivity and competitiveness of China's agricultural machinery industry.

Given the evidence on the important role of production subsidies in encouraging R&D investment, stimulating innovation outputs, and facilitating productivity, policymakers need to explore more aggressive production-subsidy policies and focus on the potential effect of other direct support policies to manufacturing companies, while it may violate WTO agreement and dissatisfactory of the U.S. or European governments.

In terms of public R&D, Public and private sector should be differentiated in research areas. Basic or "pre-technology" research should be the primary purpose for public R&D while leaving more applied research and product development to the private sector.

Joint-ventures with foreign/oversea capital or national capital have positive effects on R&D investment and innovation production. Since FDI works as an important channel to transfer technology to domestic industry, general policies should be formulated to maximize the benefits of spillovers from FDI and to encourage FDI by internalizing the spillovers for foreign companies. In terms of the state capital, SOEs reform has rejuvenated traditional SOEs through the introduction of private capitals and encouraging them to convert into joint stock companies. Therefore, policymakers need to keep focusing on SOEs reform.

To improve intangible assets accumulation, a well-developed system of intellectual property protection is necessary. It can protect intellectual property and intangible assets by reducing the high risk of infringement, as well as avoiding high litigation and time costs in legal processes. To boost fixed assets, public funding, a beneficial tax arrangement are potentially efficient and powerful tools for policymakers to consider deploying.

In a word, this research attempts to investigate the relationship between R&D investment, innovation outputs and firm productivity using Chinese firm-level data. Future works could extend the innovation framework by using longer periods of observation, by considering more types of innovation, by finding better proxies for public supports.

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