Norwegian School of Economics
Bergen, Spring 2019

China Catching Up in EV-related Technologies

Evidence from patent quality analysis

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Master Thesis, Master of Business and Administration

Energy, Natural Resources and the Environment

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1. Executive summary

Developing countries technologically catching up with leading countries within sectoral systems exhibit a set of common patterns, besides a series of case-specific behaviours. The attention that China has increasingly dedicated to the growth of the indigenous automotive sector and the development of technologies related to Electric Vehicles (EVs) shows the emergence of a specific set of common patterns identified in the catching up literature. In particular, a major role appears to be played by access to foreign knowledge and by active government policies, a manifestation of the Chinese national innovation system. In order to verify whether China is actually technologically catching up in EV-related technologies, this work carries out an empirical analysis on a commonly accepted proxy of knowledge stock: patents. Through an analysis of indicators of the quality of patents, the results show that Chinese inventors generally file low-quality inventions compared to developed countries in the sector, namely USA, Japan and Germany. However, an interesting finding is represented by the analysis of the trajectory followed by the chosen indicators over time. It emerges that China is increasing the quality of its knowledge stock in these technologies, especially with respect to core-technologies like batteries. Exploring this trend more in depth, the entities that emerge in this respect are mainly companies, not many of which seek international expansion. The depicted picture suggests that Chinese companies are currently more focused on developing solid competences regarding key technologies within national borders.

2. Introduction

The automotive industry is currently experiencing major technological changes. The future of the industry will be marked by alterations regarding a technological and organizational aspects. In particular, PwC (2018) describes the future of the industry with five adjectives: electrified, autonomous, shared, connected and yearly updated. Therefore, major shifts in the technological paradigm are expected, and these will shape the automotive industry in a whole new way. In particular, incumbent manufacturers worldwide are likely to be heavily impacted by the first mentioned trend: electrification. Indeed, the competencies that traditional manufacturers have acquired through decades about the main components of internal combustion engine (ICE) vehicles are going to be replaced by the ones relative to the functioning of electric vehicles (EVs), means of transport that rely on a new core technology: batteries.

The change in central technological knowhow is likely to have implications on the global structure of the industry and on its competitive landscape. Is there some country trying to seize this window of opportunity? The attention that China dedicated to the sector is an element that needs to be taken into consideration, for two main reasons. Firstly, China is the largest automobile market both by demand and supply (Statista, 2019) and recently became the first market for EVs, with sales in 2017 constituting half of the new-energy vehicles sold worldwide (Ren, 2018). Secondly, the Chinese government has put in place a set of policies with the stated aim of developing indigenous technological know-how in a group of key selected industries, among which EVs.

The primary aim of this work is therefore answering the following question:

Is China technologically catching up in EV-related technologies?

With catching up referring to the phenomenon of developing countries making efforts to close the technological gap with leading countries (Malerba et al., 2011).

The above question assumes that China has been lagging behind international competitors in the sector. Thus, the background and the initial empirical part of this work will preliminarily show that technology-wise China has not been a high achiever in this field.

However, why is this a question worth answering? The implications of China technologically catching up to incumbent countries in EV-related technologies are twofold. Firstly, a change in technological leadership would translate in a loss of prosperity for incumbents. In fact, being the automobile industry a high-tech sector, it is a major source of high salaries. For instance, in the US, high tech industries pay their employees approximately 75% more than other sectors. The loss in market share in such key industries would also cause national currencies to fall in relative value, with implications on the value of imports and living standards (Atkinson et al., 2019).

Secondly, losing competitive edge in high-tech industries has high costs for firms. In fact, in order to regain technological advantage, high investments in R&D are needed. At the same time, a loss in technological leadership has implications on market share, and therefore on sales. A decrease in sales would likely cause a decrease in profits for companies in the sector and would make it more challenging for them to find resources to invest in new technological know-how in order to regain competitive edge. Therefore, a death spiral-mechanism might be initiated, and returning to a leadership position might require extraordinary measures, such as government intervention.

The way the research question is going to be addressed consists of the following steps. The concept of technological catching up relies on an extensive literature regarding the phases developing countries go through in order to leapfrog incumbents. In particular, assessing whether technological catching up has happened or not relates to a country's technological output. A commonly accepted approach to measure technological output is looking at patent data. The literature on patent analysis identifies a set of indicators aimed at measuring the quality of a patent. In fact, simple patent count is not a proper measure of technological output, but rather of technological input, as it is proportional to the amount of R&D investments. Patent quality analysis instead focuses on the level of knowledge created by the inventor and its influence on future patent production. Therefore, in order to answer the research question using an analytical approach, it can be reformulated (with no major change in meaning) as:

Are Chinese patents on EV-related technologies increasing in quality?

The main findings from this work suggest that Chinese entities have been underperforming in terms of quality of produced knowhow. However, the trend is experiencing a change, especially after China joined the World Trade Organization in 2001. Results show that China is on the trajectory to leapfrog incumbent countries in the industry, represented by the US, Japan and Germany. In order to provide a more complete picture of this process, the last section of the empirical part will be aimed at identifying the Chinese entities that are likely to lead in such trajectory. Findings on this last section show that the focus Chinese entities have is well-defined technology-wise. They tend to patent all in the same cohort of key technologies. Moreover, there is a clear definition between entities that are high-achievers in terms of patent production and companies that tend to seek geographical expansion. From such results it is not easy to determine what Chinese entities will play a major role in the catching up trajectory. There is one exception to this general trend, represented by BYD. This company in fact both shows the eagerness to expand internationally, and at the same time presents a tendency to file high-quality patents.

Market considerations on the demand-side of the EV-industry are ruled out of this study. Therefore, all the considerations regarding the rate of adoption of EVs and the determinants of its demand are not explored. Moreover, reflections on the development on the charging infrastructure and on related industries are excluded from the analysis. Instead, the focus will be on examining the development of technological knowhow over time, and the characterization of the companies that lead in this respect.

The contribution of this work is twofold. It extensively applies patent quality analysis to a specific sector, something that has limited instances in the literature. I will use three commonly accepted indicators in the literature of patent value to offer a dynamic perspective of catching up over time, which is something that has been proposed in the patent quality literature but has not been applied to the field of catching up so far. Lastly, I will characterize the profile of the Chinese companies that present high quality knowhow and identify the patterns relative to those.

My analysis is useful to a variety of stakeholders involved in such emerging industry. Above all, consultants in the EV industry, since my work provides tangible proof that China is on its way to develop high-tech knowhow in the field. This is relevant as it means that Chinese firms are to be considered not as mere imitators nor serial patentors, but active contributors to the development of this industry. This is of special importance to incumbent firms in the sector, as this is a trend that is likely to affect their market share, both in the short-medium term if they are planning to expand to China, and in the long-term when Chinese firms will have accumulated enough knowhow to be competitive internationally.

Lastly, my contribution is relevant to management professionals of EV-firms both in developing and developed countries. When laying out a strategy in order to address the increasing competition in the country, my work clearly signals from which firms high-quality technological knowhow comes from. This is relevant both to respond through internal R&D decisions and to make decisions on initiatives such as but not limited to co-joint R&D programs and licensing technology decisions. Particularly regarding the latter, my contribution provides companies willing to enter or to expand in the Chinese market with a rule of thumb to understand what companies whose know-how is worth considering licensing from, and which other indigenous companies need instead to be licensed high-tech solutions.

The outline of the work is developed as following. Section 1 will be concerned with reviewing the relevant literature, both on catching up and on patent quality analysis. Section 2 is dedicated to providing background information firstly on the Chinese automotive industry, relating it to the patterns described in the catching up literature, and secondly on the patent system. Section 3 explains the source and treatment of patent data and motivates the choice of three patent quality indicators. Section 4 constitutes the empirical part of the study, displaying the results with the chosen indicators. It also offers an overview of the companies that appeared to be the highest achieving ones in the cohort. Section 5 briefly discusses the results and contains the conclusions of the whole work.

3. Literature review

3.1 Catching up

The concept of catching up was initially introduced in a merely economic context as a process that involved developed and developing countries. Abramovitz (1986) defines it as an opportunity of follower countries to catch-up with leaders in terms of national productivity levels. In particular, the wider the gap between two countries, the greater the potential for catching up. However, such potential can be actually exploited by the follower only if he is provided with "social capability", defined as the ability of implementing technologies that are already present in leading countries. This review is going to focus on an "assimilative" view of catching up, rather than on an "accumulative" one (Nelson et al., 2000). According to accumulative theories, investments in physical and human capital automatically brings countries to catch up with world economic leaders. However, the view shared in this thesis is that the process of catching up requires an active learning process and innovative activities from the follower's side. This view has been named "assimilation theory" by Nelson (2000).

Even though Abramovitz's approach to catching up refers to productivity measures, evidence shows that technological progress is strictly linked with economic development. More precisely, economic growth can be explained looking at the follower's efforts in both imitation and innovative activities (Fagerbeg, 1987).

Fagerbeg et al. (2004) argue that, in order to catch up, it is not sufficient to adopt the same techniques as in the leading countries. Catching up can occur only if the follower is able to innovate in the organizations and in emerging industries. In particular, Gerschenkron (1962) introduces the idea that catching up with a leading country economy can be achieved by investing in new technologies which can be implemented in "progressive, dynamic industries". Through investments in equipment in those specific industries, the developing country usually aims at becoming internationally competitive in that particular field.

The elements that determine catching up in a specific sector are the actors, the knowledge base and the institutions. The actors involved are not limited to business firms, but a broader range of entities that are part of a network or a cluster, such as suppliers, university and public research centres, financial organizations and governments. Different actors are provided with different knowledge bases that might or might not be smoothly transferred from firm to firm. Technological diffusion in principle could happen easily if there were no barriers to its dissemination and developing countries could easily identify the most advanced technologies and catch up with leading countries. However, a more down-to-earth view conveys that technological diffusion is "neither costless nor unconditional". For this reason, technological transfer might be only partial, as the developing country incurs in costs to adopt the new technology (Fu et. al, 2010). Additionally, the interactions among actors are influenced by laws and standards, commonly indicated as institutions, which are able to determine whether the environment in a specific sector is suitable to perform catching up (Malerba et al., 2011).

Moving to a sectoral view of catching up, Malerba et al. (2011) show that there are identifiable patterns across different sectors, but at the same time sectoral difference can determine or impede its occurrence in a specific industry. In fact, catching up is also influenced by a set of national and circumstantial issues that are extremely context-specific and that may hamper the focus on emerging sectors, such as the means for the diffusion of knowledge, the conditions that determine structural change in the industries, the macroeconomic and monetary settings and the distance from the technological frontier (Abramovitz, 1986; Fagerbeg et al., 2004).

Catching up across different sectors can follow different dynamics, but there are four elements that according to Malerba et al. (2011) commonly characterize such process, namely firms learning, access to foreign know-how, skilled human capital and active government policy. This classification is useful to gather different contributions concerning catching up focusing on specific factors.

3.1.1 Firms learning

Learning is a crucial matter when studying catching up (Nelson, 2007). Mere catching up is not a synonymous of copying, as productive practices have to be adapted to indigenous conditions. Schnaar (1994) classifies different kinds of imitation on the basis of the share of their original content. The least original are counterfeits, also known as duplicative imitations. This kind of imitations does not hold any competitive advantage per se. Duplicative imitations might result in being competitive with the originals uniquely on the price. On the opposite side of the spectrum is technological leapfrogging and the adaptation of an existing technology to a new industry. For instance, basic technological knowledge can be drawn practising reverse-engineering on more advanced technologies (Nelson et al., 2000). Nevertheless, in order for learning to occur, investments in local R&D are needed. Therefore, on the path to catching up, the follower is involved in an active learning effort. Enablers of the process of catching up include “capabilities to access complementary assets, absorptive capabilities and innovation capabilities”. They are all required to successfully adapt technologies which originated elsewhere to a specific context and to pursue capability upgrading. (Malerba et al., 2011).

3.1.2 Access to foreign know-how

Access to foreign know-how is another common element of the pattern since it allows the country to “be fed” with advanced technologies. The channels through which this is accessible varies from country to country and from sector to sector. In general, foreign know-how is a major driver of productivity growth in developing countries, as a high share of innovation activities is located in the US, Europe or Japan (Fu et al., 2010). The dissemination of technology across firms and regions can be intentional or even unintentional and it happens in a variety of ways, including imports, foreign direct investments (FDI), migration, research collaborations, media and integration of value chains (Pietrobelli, 1996). Fu et al. offer an insight especially on FDI coming from developed countries. They highlight how they enable technology transfers into a developing country, but at the same time they come with negative consequences for the target country. In fact, if on one side FDI increases competition and helps in selecting the most technologically advanced firms, on the other side it hampers the development of indigenous firms and even drives the existing ones out of the market. Consequently, the indigenous effort in R&D might experience a significant drop (Fu et. al, 2010). Lall (2003) argues that the more technologically advanced a developing country becomes, the greater the importance of indigenous innovation as compared to foreign innovation. In other words, know-how coming from abroad is useful to introduce a certain kind of technology in a developing country, but after that it increasingly depends on the indigenous efforts how those new capabilities are going to be deepened.

Additionally, it is worth considering that, as Fu et al. (2010) do, not all superior technologies coming from foreign countries can find an adaptation in developing countries. For instance, a country whose productivity is mainly determined by un-skilled and semi-skilled labour will less likely find useful foreign industrial technologies, favouring indigenous labour-augmenting technologies over those. Know-how coming from developed countries might be more suitable in technology-intensive sectors that employed qualified labour. However, evidence shows that different industries, depending on whether they are high or low-tech, can be dominated by either foreign or indigenous technology.

In general, foreign and indigenous technologies play different roles in the catching up process, but they are both necessary in order for it to happen. That is the reason why Fu et. al conclude that indigenous and foreign innovation efforts are complementary.

3.1.3 Skilled human capital

Evidence from Fagerbeg et al. (2004) shows that skilled human capital is an essential element in the catching up process, as it enables the development of necessary absortive capacities (Fu et. al, 2011). Countries that successfully caught up in emerging industries concretized their efforts to achieve their goals in investments in higher education and technological R&D.

3.1.4 Active government policies

A pivotal role in the process of catching up is played by the national innovation system, namely the set of decision-makers' beliefs regarding the role of technology in economic progress and the capabilities that are to be developed, that eventually shape the priorities of a country (Malerba et al. 2011). A national innovation system is expressed by how a certain government acts with respect to technological innovation.

Active government policies have encouraged the learning process and capability formation across sectors (Malerba et al., 2011). This role is even more crucial in developing countries, since the financial markets might be deficient, and there might not be much space to catch up and compete with incumbents in developed countries. Therefore, the state holds the function of supporting indigenous firms, particularly in the initial stages of market and technological development (Lee et al., 2009). Fagerberg et. al (2004) highlight how Asian economies have historically adopted a Gerschenkronian approach to catching up with Western countries, focusing on few, promising industries.

3.2 Indicators of innovativeness and patent quality

Simple Patent Count (SPC) is sometimes used as a proxy of the innovativeness of an entity or a country in a specific technological field. However, the mere count is not sufficient to provide a reliable measure of the value of the knowhow created. That is because there are a number of reasons why subjects decide to patent, many of them not even related to technological breakthrough.

According the survey carried out by Sampat (2018) across a variety of industries, the main reasons why companies decide to patent are preventing copying, patent blocking, preventing suits and being able to use patents in negotiations. Moreover, patents are not among the tools that companies prefer to secure appropriability of their own invention. Instead, other means such as lead time, secrecy and complementary assets are preferred. In some industries, such as ICT, patents are actually recognized as an ineffective tool for protecting the returns from innovation (Sampat, 2018). When counting patents as a measure of innovativeness of a country, all the mentioned factors are not taken into consideration. Counting patents that are only used for strategic purposes might cause to depict a distorted overview of technological upper hand. For these reasons, the definition of the value of a patent or, equivalently, its quality, are needed in order to assess the inventiveness and innovativeness of a country.

A high-quality patent from an economic perspective is defined as a patent that accomplishes the goals of a patent system, namely encouraging innovation while enabling diffusion of technological advances. It is in the interest of countries to produce high quality patents in order to avoid market failures. Indeed, low-quality patents are more likely to be faced in court, which constitutes a social cost. In fact, the presence of such risk is what hampers the effort to innovate since it leads to higher uncertainty (Squicciarini et al., 2013).

Squicciarini et al. (2013) provides a wide collection of indicators, from which I selected three to carry out my analysis: patent family size, forward citations and backward citations. Firstly, I looked at patent family size in order to depict the current situation with respect to patent quality with a simple indicator. Subsequently, I went more in depth on the issue looking at the number of forward and backward citations each patent received, since they appear to be among the most commonly accepted measures of patent quality. The latter two indicators also give a broader picture of the development of patent quality over the time window and allow to monitor compare the behaviour of all the countries taken into consideration. Harhoff et al.

(2003) show how crucial it is to present a variety of different indicators in order to assess as accurately as possible the value of a patent. They rely both on citation-based indicators and other measures, including family size. The literature offers a variety of points of view on these and other indicators, which I will review in the following section.

4. Background

4.1 Patterns of catching up in the Chinese automotive industry

Overall, Altenburg et al. (2017) have an optimistic view on the possibilities that China has to put into place a technological upgrade in the field of electric vehicles. Firstly, they claim that Chinese companies can rely on the dimensions of the Chinese market in related supply chain products, and this is also likely to attract increasing foreign direct investments. Secondly, they believe that exporting low-priced EVs to countries with similar demand and conditions is an opportunity that Chinese players are likely to seize. Lastly, the Chinese government has recognized the importance of nurturing technological know-how in the field. Consequently, there has been an increasing emphasis on research and development, besides the establishment of technological standards. However, has China shown consistencies with the patterns depicted in the literature when it comes to catching up in a sector? The answer is affirmative, but the case holds its peculiarities. More specifically, there are extensive examples of two components from the catching up literature: China trying to access foreign knowhow and active governmental policies in order to encourage indigenous innovation. However, the emergence of indipendent automakers was driven by other case-specific factors.

4.1.1 Access to foreign knowhow: Joint-ventures

The automotive industry in China was heavily influenced by the opening policy started by Deng Xiaoping in the 1980s. He drove the Chinese shift from socialism to a more capitalistic economic system. Before this policy was put into practice, the type of vehicles that the Chinese automotive industry could be considered competitive on were mainly trucks and buses. The opening up policy gave a great boost in private vehicle demand, which in turn led to an increase in imports of foreign vehicles (Dunne, 2016).

Foreign companies started to realize the potential of such a huge market, and therefore were increasingly eager to establish branches of their businesses in mainland China. The Chinese government saw mainly two opportunities in such a setting: the possibility of bringing forward its opening up economic policy and learning more about the technology side of vehicle manufacturing from foreign companies. Moreover, by 1994 the Chinese government officially identified automotive as one the pillar industries of its economy from then on (Zhang et al., 2001). In order to concretely seize the opportunities deriving from the expansion of the market, two policies were levied: the Chinese Automobile Industry Policy in 1994 and the Chinese Automobile Industry Development Policy in 2004 (Traub-Merz, 2017). These started China's joint ventures policies in the sector as a tool to surf the growth of the market. The rationale behind establishing joint ventures with foreign companies was mainly enabling industrial development, when potentially also attracting investments from overseas (Zhang et al., 2001).

Essentially, foreign companies operating in the Chinese market had to establish a maximum of two joint ventures with local automotive companies, making sure that their equity share was less than 50%. This way, the Chinese government was aiming to protect Chinese brands and to keep control over the industry. The first joint venture of this kind to be set up was the one between Beijing Jeep Automobile Co. Ltd. (BAW) and AMC in 1984, where BAW owned 57.6% of the shares.

This strategy was originally meant to benefit indigenous companies, namely State-Owned Enterprises (SOEs) like the "Big Four": Shanghai Automotive Industry Corporation (SAIC), Dongfeng Motor, First Auto Works Group (FAW) and Chang'An. However, the policies resulted in being more beneficial for foreign companies. This was due to two factors: the first is that, even though joint ventures were built with 50-50 arrangements, final products were sold with the foreign brand name. This was a low-risk strategy from Chinese automakers' perspective, because they could exploit the foreign brand to sell proven-successful designs. However, this hampered the opportunity for them to establish their own brands in the market. Secondly, interests of the two parties in joint-ventures were highly misaligned. On one hand, Chinese companies wanted to drain technological know-how from foreigners, while these had no interest whatsoever in sharing relevant technological knowledge, they just wanted to seize the opportunity of entering the huge Chinese market. As a result, joint ventures were built so that Chinese companies would be in charge of the assembly operations, while foreign companies dealt with design innovation and branding of the product. Thus, the Chinese counterparty was never revealed the outcome of the ongoing R&D projects on the most cutting-edge technology and on the new product development processes. Instead, foreign partners tended to provide their Chinese counterparties with old platform technologies in case they were pressured by the Chinese government (Chang, 2016). An example of such situation is given by SAIC, that decided to suspend R&D activities and just outsource them to Volkswagen, its joint venture foreign partner firm. This is the result of a failed attempt in internalizing valuable technological know-how (Ahrens, 2013).

However, the Chinese government managed to design a shift towards a stricter regime regarding joint ventures, in order to allow indigenous companies to benefit more from them. With the increasing attention that EV-related technologies gained in the government's agenda, existing joint ventures were renewed and car manufacturers operating in China were imposed to produce a certain share of EVs. Moreover, in order to encourage a more consistent knowledge transfer as compared to how it occurred with traditional automotive, the technology originated in the joint venture had to be jointly owned by the two parties (Dunne, 2016). Therefore, the Chinese government made multiple attempts to create channels to allow indigenous firms to access foreign knowhow, a vital component of the catching up process, according to the literature.

4.1.2 Active government policies: Indigenous innovations

The Chinese government has gradually shifted its attention towards favouring electric vehicles over internal combustion engine vehicles for a variety of reasons, that pertain both to the future of the industry itself and the impacts on air quality in the country. According to Howell et al. (2014), there at least three reasons why China is motivated to promote the growth of the sector. Firstly, it is an opportunity for an economic upgrade. In fact, the development of the industry has been depending on foreign knowhow, and therefore has led China to fall into the "middle-income trap", where it cannot greatly contribute to the global value chain through consistent added value (Zhang et al., 2001). Pursuing technological upgrade would instead bring China to be more competitive internationally on this perspective. Secondly, China heavily relies on imports for energy consumption, as around half of its oil comes from overseas. In particular, large part of if comes from Saudi Arabia. Therefore, it is both a matter of cost, as China is overall a net importer of energy, it is also risky since the sources from which this comes from are not widely differentiated. The shift to electric vehicles is therefore part of a bigger picture where China is trying to promote the development of indigenous conventional and new energy sources. Thirdly, Chinese cities face major issues when it comes to local pollution. In fact, while EVs do not have tailpipe emissions, electric powerplants are still responsible for smokestacks. Therefore, there would be a redistribution of urban pollution, pointing outside of Chinese cities (Howell, 2013; Altenburg, 2017).

The Chinese government has laid out several policies in order to encourage the development of EVs in the country. Overall, the areas that are targeted by EVs governmental policies concern the charging network, sustainable mobility projects, increase demand for EVs and encourage research and development on EV-related technologies. The review of Chinese policies will focus on this last point, being the aim of this study related to technological catching up.

Since 1963, China has paced its social and economic development with Five-year plans, a state-planning tool it inherited from a Soviet-style government. The purpose of a Five-year plan is establishing guidelines regarding a variety of different aspects, from social and economic, to cultural and educational ones. The goals set out in a plan are both qualitative and quantitative and comprise a complete range of economic actors, such as but not limited to the government itself, universities, companies and agencies. Five-year Plans are therefore a blueprint that more specific policies can be developed on (Huang, 2015).

The attention towards the automobile industry firstly emerged in the 10th Five-year plan (2001-2005) and the level of detail has increased with the subsequent ones. The way the plan touched on the sector is through encouragement in further technical development. In particular "*Enhancing traditional industries with high, new and advanced technologies*", supporting companies with the final aim of improving product quality and reducing pollution and waste (Zhu, 2001). The National High Technology Program (also known as "863" program, as it originated in March 1986), started by the Ministry of Science and Technology, was thought as a strategic national R&D program to allow China to start competing internationally on high-technology trends. During the 10^{th} Five-year Plan, the 863 program was a concrete tool through which the government first started to encourage indigenous companies to leapfrog developed countries in a set of strategic industries. They were organized in four priority projects, and among them the areas of "energy resources and environmental protection", in harmony with the overarching Five-year Plan. At the beginning of each Five-Year Plan, project 863 is renewed, each and every time specifying the amount of funding that should be granted for those strategic high-tech sectors both by central and local governments (Zhang et al., 2014).

Since 2009, China has published 39 policies specifically related to EVs revealing that the sector is attracting concrete efforts of the central government to create Chinese leadership in the field. What is interesting to notice is that 15% of the published policies involve R&D support, and they have all been published between 2015 and 2016 (Li, 2017). Therefore, it is reasonable to assume that companies in the sector are likely to increase their investments in R&D activities. For this reason, the results coming from this study, that focuses on the 1991-

2014 time-window, in terms of technological catching up can be considered conservative with respect to what the outlook of the knowledge stock Chinese companies will be able to nurture.

The 12^{th} year plan (2011-2015) reached a higher level of detail by creating a framework that identified the precise technologies that national R&D should focus on. Firstly, the types of vehicles that should receive closer attention from this perspective were highlighted: Hybrid Electric Vehicles (HEV), Electric Driving Vehicles (namely BEV, PHEV and REEV) and Fuel Cell Electric Vehicles (FCEV). Subsequently, the set of key technologies that were relevant for the mentioned types of vehicles where identified: energy storage devices, electric motors and technologies for electronic control (Du et al., 2013; Zhang et al., 2014).

As the empirical part of this work is carried out looking at patent data, it is crucial to mention one major change China has experienced in its intellectual property system (IPR). In 2001 China officially joined the World Trade Organization (WTO). Along with the further opening up of its economy, this event determined the entrance of China in the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement. This sets international standards with respect to intellectual property rights and their enforcement. In particular, it harmonized the requirements for patentability of an invention, establishing it has necessarily has to be novel, useful and industrially applicable. China has implemented the agreement translating it into a set of national laws, reforming its Patent Law, Trademark Law and Copyright Law.

4.1.3 The emergence of the young tigers

The Chinese automotive industry was surey influenced by the literature components of catching up, especially as far as acces to foreign knowhow and active government policies are concerned. However, there is a category of companies in the market that initially was not influenced by the benefits of either of those two phenomena, but nevertheless managed to establish itself in the market. These companies are indigenous carmakers usually called young tigers. They managed to grow thanks to a combination of reverse-engineering practices, attraction of engineering human capital from competitors and alternative market strategies.

The attention that SOEs gained through public policies initially hampered the emergence of new independent automakers, that did not exist before the joint ventures policies. Initially they were not allowed to form agreements with foreign companies, since that was a privilege reserved to SOEs. Despite the initial lack of support from Chinese authorities, indigenous independent car makers managed to emerge around 2000 firstly seizing the fast-growing market demand for private vehicles coming from the Chinese middle-class and from citizens in rural areas, and secondly thanks do the loosening of the regulation on car production licenses (Luo, 2005). These independent car makers are sometimes referred to as the “young tigers”, because they are relatively new companies that managed to establish themselves as competitors to existing SOEs. They mainly come from three different backgrounds: they were either motorcycle companies that decided to convert their business, like Geely; some of them were newly established automotive companies funded with capital coming from other industries, such as consumer electronics. An example in this latter category is BYD. Lastly, young tigers originated also from component manufacturing companies, like Chery.

The way young tigers managed to enter the Chinese automotive market was firstly marketing their products right away with indigenous brands. As per the know-how side, they relied on attracting engineers from SOEs, outsourcing R&D and reverse engineering foreign car models (Chang, 2016; Luo, 2005). These sources of knowledge brought the companies to develop low-cost vehicles with less sophisticated technologies, mainly targeted at rural users and other price-sensitive segments. However, recent developments such as Geely’s purchase of Volvo in 2010, reveal that these companies are actually making an effort to upgrade their production, as the low-end segment is not sufficiently profitable (Chang, 2016).

Since young tigers have faced intense competition in the Chinese market from their very first steps, they were more eager to seek opportunities abroad: they started exporting soon after their products were launched in China. In 2004, about all the exports of Chinese sedans came from Geely and Chery (Luo, 2005).

4.2 Patents and patent quality

4.2.1 Patents and patentability

According to the definition provided by WIPO, a patent is "*a document, issued, upon application, by a government office (or a regional office acting for several countries), which describes an invention and creates a legal situation in which the patented invention can normally only be exploited (manufactured, used, sold, imported) with the authorization of the owner of the patent*" (WIPO, 2017a). Thus, a patent creates a monopoly situation, in which the invention can only be taken advantage of by the owner of the patent. More precisely, it prevents others from commercially exploiting the patent's owner invention without his authorization. If other subjects are willing to exploit the invention, they will have to obtain the explicit authorization of the patentor. This mechanism aims at accomplishing the first objective of a patent system, which is giving incentive to companies and individuals to produce new knowledge. In fact, after his intellectual effort, the patentor can derive economic benefits from his invention. In this respect, the patent system defends the legal position of the subjects and gives them the right to exploit what they have created themselves. However, this right needs to be balanced with the right that society has to benefit from the newly produced knowhow as well. Thus, here comes into play the second objective of a patent system, which is allowing society to take advantage from the technological breakthrough brought by the invention. The way in which the patent system accomplishes this second objective is concretized in two steps: first, one of the requirements for patentability is the clear disclosure of the knowhow and subsequent publication by the Patent Office once the patent is granted. This aims at enabling knowledge transfer and at creating additional opportunities for innovation and technological development (WIPO, 2002). Second, patents prevent others from commercially exploiting the invention only for a limited amount of time, usually 20 years, which can vary for other types of intellectual property rights, such as utility models. Patent systems are regulated through national regulations and by international multilateral treaties. The most influential ones are the Paris Convention and the TRIPS Agreement (WIPO, 2002).

There are a set of four conditions that make an invention patentable: it has to concern patentable subject matter, it has to be useful, novel and be non-obvious. Moreover, the invention has to be clearly disclosed in the application.

Article 27 of the TRIPS agreement defines the concept of patentable subject matter in a negative way, meaning that is excludes the fields of technology where a patent application cannot be filed. These include, besides inventions that go against public order and morality, "*discoveries of materials or substances already existing in nature, scientific theories or mathematical methods, plants and animals […], schemes, rules or methods […] and methods of treatment for humans or animals […]*" (TRIPS, 1994).

The utility prerequisite is also defined as industrial applicability, and it indicates that the invention cannot be only theoretical, it needs to have practical use cases.

Novelty is also defined negatively: an invention satisfies this requirement if it does not anticipate any prior art. Only the lack of novelty can be proved, demonstrating that the invention pertains to existing knowledge in the field that has already been disclosed in either oral or written form.

The fourth and last requirement is non-obviousness, also defined as inventive step. It entails that the invention should not be obvious for a person having ordinary skill, thus not the best expert, in the art. This means that the invention should involve some degree of creativity and that the step forward with respect to existing knowhow is noticeable

4.2.2 Procedure for patent application

The first step when drafting a patent application is identifying the invention. In practice, it means that all its features have to be described and their role in solving a specific problem should be explicated. Moreover, it should be explained why the patent fulfils the above explained requirements.

Afterwards, the application is filed at the Patent Office and the examination phase starts. First, a formal check is performed right after the application is assigned a filing date. This is a crucial feature of a patent, since within 12 months the patentor can claim priority for that filing date in another country which is party in the Paris Convention or TRIPS agreement. Once such "examination as to form" is complete, the search phase begins. This is carried out by the Patent Office, and its ultimate goal is defining the prior art in which the patent application can be placed in. Additionally, it assures that the presented solution is not existent or at least not to similar to existing patents in the same technological field. This process allows a better definition of the scope of rights granted with the patent. All the found documents that reveal the state of the art are disclosed to the inventor and become cited publications in the new patent application (Office of Technology Assessment and Forecast, 1976).

The last phase before the patent is published is called examination as to substance, and it aims at verifying that a patent fulfils all the patentability conditions, namely usefulness, novelty and non-obviousness. Once the patent is granted, it is inserted into the Public Register, where the content of the patent is saved. The patent is also published in printed form accessible to anyone, as it is in the collective interest (WIPO, 2017a).

4.2.3 International filings

There are mainly three alternatives for an applicants to seek patent protection abroad: filing multiple applications in the relevant Patent Offices; filing a patent application in a Paris convention country and then filing additional applications in the countries of interest, claiming priority over the filing date of the first application; lastly, an efficient alternative is filing an application under the Patent Cooperation Treaty (PCT). Such latter treaty is valid among the majority of the Paris Convention countries and is managed by WIPO. It allows applicants in the member states to obtain an “international patent” and to have the examination as to form and the search phase carried out only once. What is left to the single countries’ Patent Office is the examination as to substance of the invention. (WIPO, 2017b).

4.2.4 Utility models

Utility models are tools used to protect inventions that pertain to the mechanical field. They are different from patents in that the requirement of an inventive step is sensibly less strict than the one required to file a patent. Additionally, the window of time in which the utility model grants protection is shorter in most countries (WIPO, 2017b). In my analysis they have not been taken into account when considerations on know-how quality were being made. Only the inventions obtained on the basis of the process described in the previous section were considered strictly considered as patents. In fact, utility models, especially in China, attract “by construction” lower quality inventions. Since the requirements of their filing are far less stringent in comparison to patents in terms of inventiveness, it is arguable that utility models have allowed Chinese entities to codify imitated and low-quality knowledge, especially in the 1990s. For these reasons, utility models were favoured over patents for a long time by Chinese companies (Manderieux, 2006). Figure 1 depicts the evolution of the share of patents and the share of utility models in China in the 1991-2014 time window for EV-related patents. There is a clear substitution effect between the two intellectual property tools. Utility models constituted the majority share until 2000. From then on, their share decreased. Such trend is perfectly mirrored by the one followed by patents over time: they did not used to be a popular choice for protecting inventions on EV-related technologies, but when utility models' share started decreasing, patents started to become more common in the sector. 2010 represents the moment when the share of patents was higher of that of utility models for the first time.

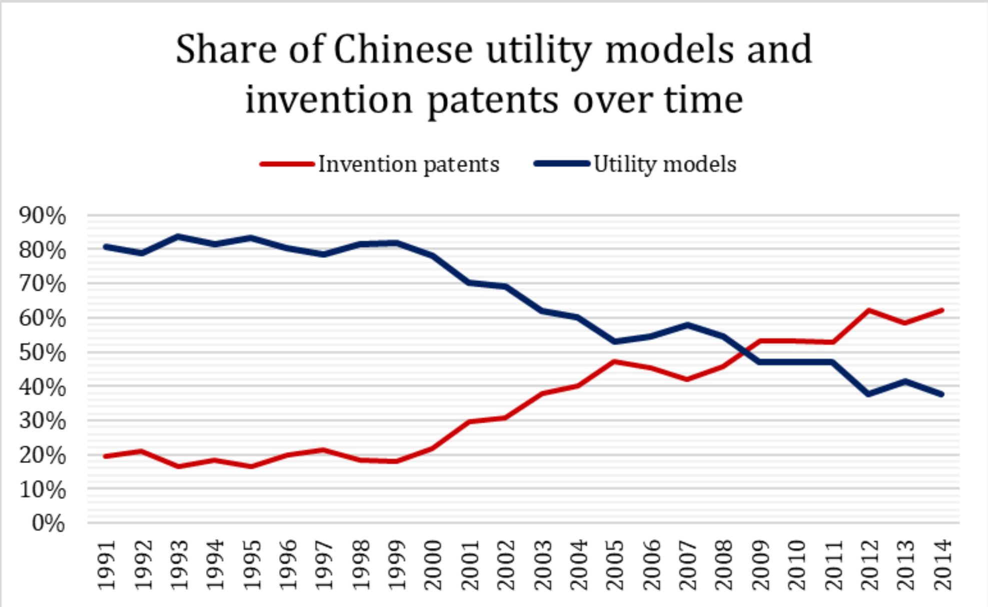

Figure 1. Share of utility models and patents in China over time

There are various factors that could have led to the rise in patent applications in the 2000s and the catching up of those with respect to utility models. Manderieux (2006) mentions a few, often highlighting the role of foreign companies. In fact, it is in the interest of the latter entering the Chinese market, both for exploiting cheap labour and for taking advantage of its dimensions. In order to do so, it means that foreign companies need to locate a portion of their business there, establishing a subsidiary for instance. In this process, knowledge transfer and research are both involved. On the other side, the entrance of foreign companies into the Chinese market leads Chinese companies to be in need for an effective framework to protect their own inventions and outputs from their own R&D. In fact, even though China has long been perceived as the "land of copycats", it is gradually experiencing the process of turning "*from an economy of imitation to an economy of innovation*" (Manderieux, 2006).

In practice, the above explained motivations have found concretization in a number of acts that China decided to carry out both nationally and internationally. Firstly, the entrance in WTO in 2001 has led China to comply with higher international standards when it comes to intellectual property rights regime (Prud'Homme, 2017). Additionally, it is worth reminding that the number of patents is a reliable proxy of the investments in R&D. Therefore, a growth in patent applications is a sign that governmental initiatives and incentives successfully encouraged R&D for the development of indigenous inventions. In general, China has improved its intellectual property legal framework by joining the TRIPS agreement and becoming a PCT International Search Authority and an International Preliminary Examination Authority. Additionally, concrete efforts have been made in order to improve the quality of enforcement, even though the risk of intellectual theft is still high, as the legislation is not without gaps (Manderieux, 2006).

4.2.5 Chinese patent quality

There is a fair number of contributions using patent quality analysis to measure the innovativeness of China and go beyond patent count as a meaningful measure, shifting instead the analysis from quantity to quality of knowhow. Thoma (2013) is among the first to assess the determinants of the quality of Chinese patents on a country level looking at patent grant rate, the number of oppositions and patent renewals. He concludes that Chinese patents are generally of lower quality than foreign ones. Other authors such as Santacreu et al. (2018) and Zhang et al. (2012) come to similar conclusions looking at other subsets of patent quality indicators, namely invention patent grants, patents filed abroad, patent renewal periods. Zhang et al. (2012) dedicate attention also to single sectors, to verify the consistency of their results and highlight sectoral peculiarities. They find that Chinese patents are more valuable in the fields of mechanical and electrical engineering.

5. Data

5.1 Data sources and variables

The data on which the empirical analysis will be carried out on is taken from PATSTAT, a database that contains bibliographical and legal status patent data from leading industrialised and developing countries. PATSTAT data is organized in sub datasets that contain information on a specific aspect regarding patent applications. Below a graphical illustration of the relationship between the datasets that have been used in this analysis.

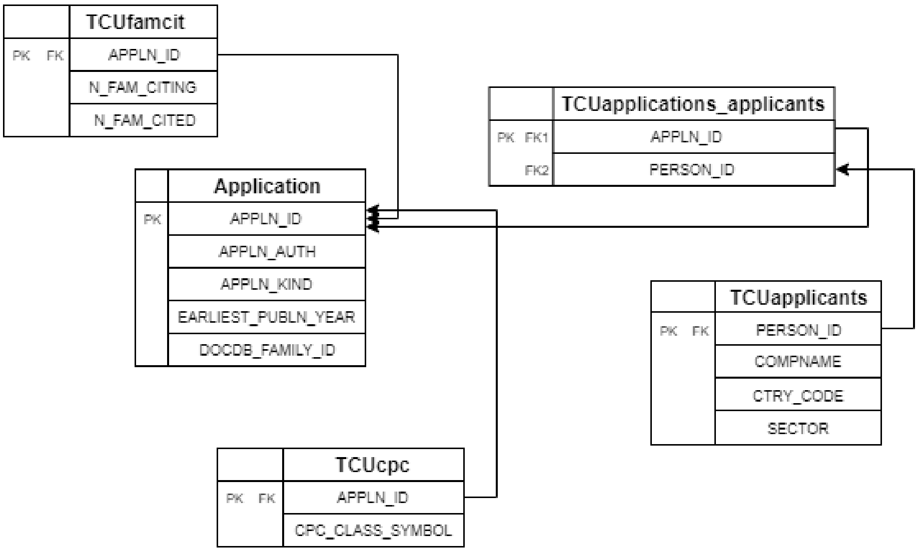

Figure 2. ERD of involved datasets

The variable that connects all the involved datasets is APPLN_ID. It is a number that is assigned to every single patent application and allows to identify it. In order to assign a nationality to a certain patent application, the information contained in TCUapplicants is leveraged. Every patent applicant is identified with a unique number (PERSON_ID) and is assigned a certain nationality. Therefore, a patent is considered Chinese if the applicant is Chinese.

When it comes to analysing data regarding patent quality, the content of the variables in TCUfamcit is considered. Citations are equal for all patent in a specific DOCBD family. This means that the unit of reference in this instance are not patent applications, but patent families. However, since different patent applications might be assigned different nationalities within a single patent family, fractional counting has been applied (OECD, 2003). This means that for every DOCBD family, the share of each nationality has been calculated. For instance, a patent family could result in being 75% Chinese and 25% American.

The datasets were filtered so to keep only the observations that concern EV-related technologies. In other words, only the patent applications that presented at least one EV-related technological class were kept in the dataset. The methodology through which the technological classes were selected is the following: In general, an initial cohort of IPC classes have been selected By Bocconi ICRIOS Research Institute on the basis of the works of Yang et al. (2013) and Pilkinton et al. (2002). Subsequently, the classes were thoroughly checked and filtered on Espacenet through the keywords: “electric vehicles”, “HEVs” and “PHEVs”. The same procedure has been followed for class Y in the CPC system. Consequently, in TCUcpc only these filtered classes are retrievable.

Before empirically verifying the growth of the value of Chinese patents, the sample has been described in the following section from multiple angles, in order to provide clearer overview of the data involved.

5.2 Descriptive statistics

This section provides a set of descriptive statistics to characterize the sample and establish a starting point for the empirical analysis. It clarifies the composition of the dataset by nationality and digs into the specificities of the trends followed by Chinese patentors. Fractional counting is applied to the statistics in this section, in order to avoid double-counting of patents.

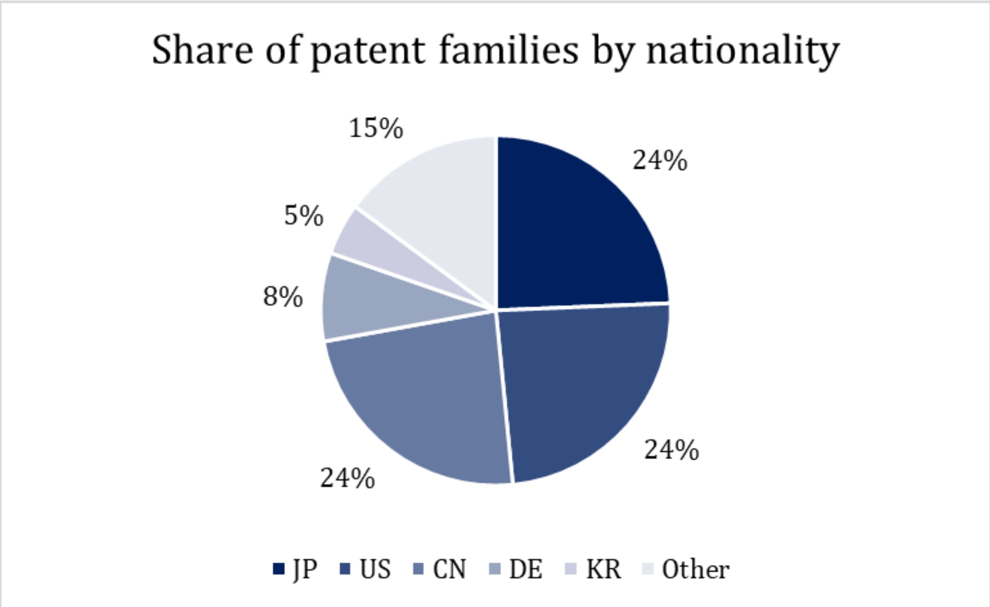

Figure 3. Nationalities in the dataset

The three nationalities that patented the most in EV-related technologies are the Japan, the US and China with their shares all equal to 24%. For this reason, the "benchmark countries" that have been selected to measure the extent of catching up of China in the sector comprise both the US and Japan. Even though its share of patents in the sample is comparatively low, Germany has also been included in the benchmark. That is because Germany has nurtured some of the most competitive companies in the automotive sector and presents one of the highest expenditures in the automotive industry (Statista, 2011).

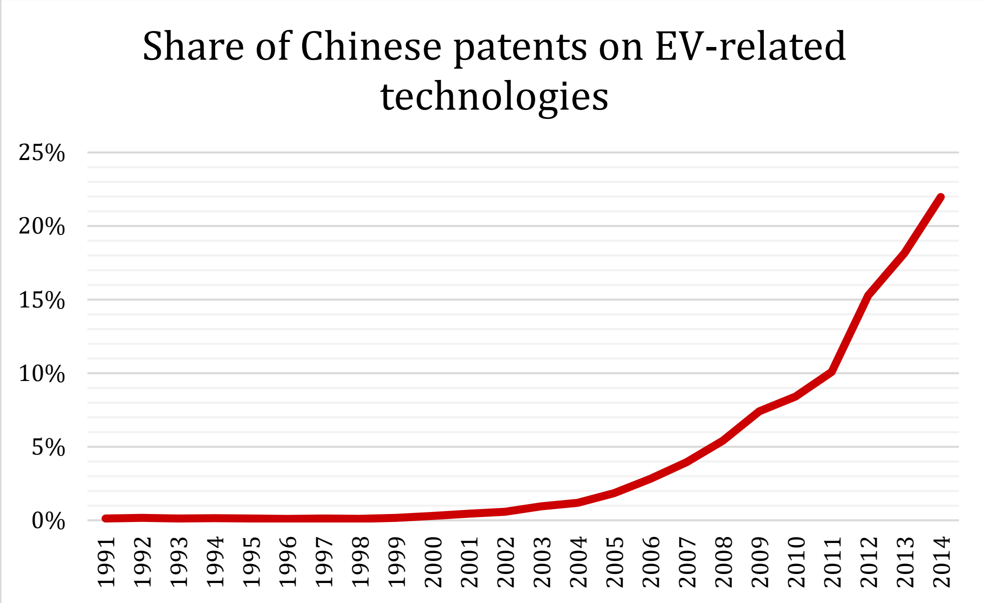

Figure 4. Share of Chinese invention patents in EV-related technologies over time

The share of Chinese invention patents in related technologies over time has evidently seen a sharp rise from the early 2000s. The entrance of the country in the WTO and the changes in the IPR law have played a role in defining this trend. As stated before, a substitution effect between utility models and invention patents has occurred. In 2014, the share of Chinese patents in the sector has reached almost one quarter of the world patent production.

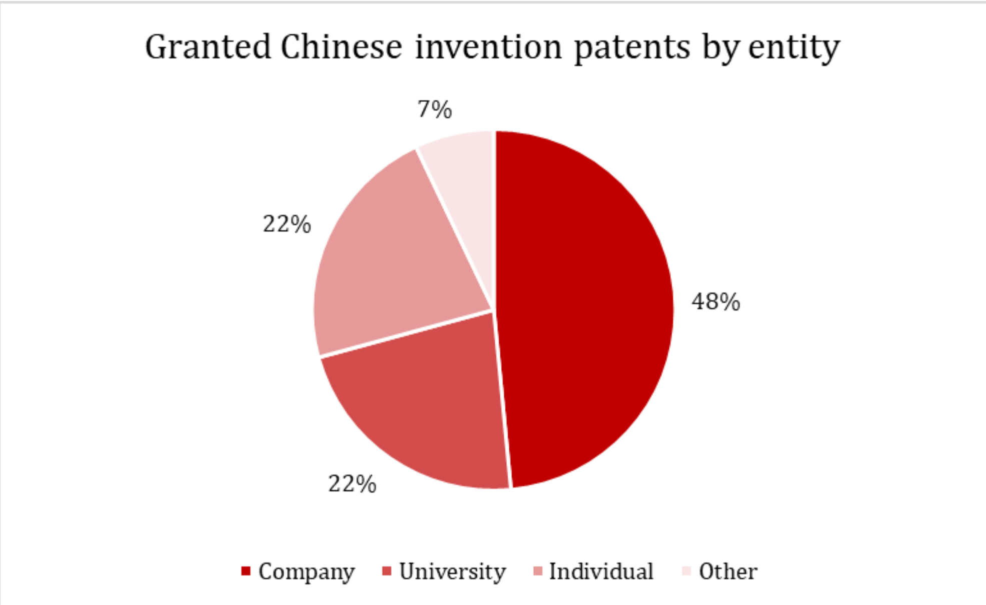

Figure 5. Chinese invention patent production by entity

As displayed in Figure 5, around half of the patents in the sample have been granted to companies, while a little less than the remaining is equally split between universities and individuals. The “other” portion comprises a variety of different non-governmental entities. Below, the entity perspective is seen from a dynamic perspective.

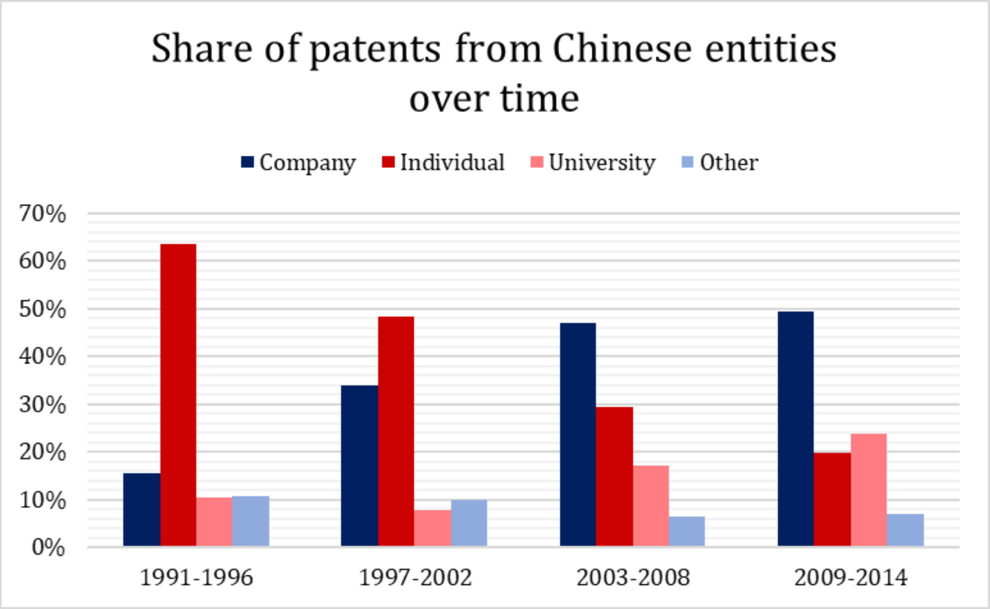

Figure 6. Dynamics of invention patent grant by entity

The graph above clearly highlights a phenomenon of “institutionalization” of patent ownership, as it shifts from individuals to companies. This could be due to a number of reasons, including the mere change in the habits or the system adopted by companies regarding the name of an applicant. It could be that in the past they were more inclined to file the patent with the name of the inventor rather than the name of the company. Alternatively, it could be that companies were not filing a large number of patents in the past, and this again could be related to the favourable regime that utility models used to be characterized with. In general, this result suggests that examining the results on patent quality might be more interesting for patents filed by companies, as they seem to be the ones that gained a leadership position in Chinese patent production in the field.

5.3 Standardization

Each family of patents in the dataset is associated with the number of forward and backward citations. As previously stated, these are two measures of the quality of a patent and they are going to be examined in my analysis. However, in order to be able to compare the number of citations between different years and draw conclusions on the evolution of citations over time, the absolute number of forward citations has been standardized dividing by the mean of the citations for each year. Dividing by a yearly measure allows to control for any change in the citation propensity over time and the "inflation" of patents that might have occurred over time. An instance of highly increased patent propensity is given by Hall et al. (2001), who studied the patent explosion in the US. Such anomalous surge in the number of patents was caused by reforms in the patent system, in particular by the Boyh_Dole Act in 1980, that allowed the expansion of the patentable subject matter and at the same time granted a higher level of patent protection. Patent policy and other factors can alter the filing behaviour in a given country over a period of time, therefore standardization by year is necessary to observe the development of trends over time.

Hall et al. (2001) point out that standardization should be done also by technological field. However, since the dataset has been already filtered by "technological area", through a preliminary key-word search, it is acceptable to skip the standardization by technological class.

In the literature, yearly standardization is done also diving by the yearly maximum number of citations received (Squicciarini et al., 2013). In the instance of the PATSTAT dataset analysed, diving by the maximum generates a high number of small standardized values, since the distribution of citations is rightly-skewed, meaning that there are many patents with a low number of citations and few highly cited ones. Diving by the mean allows to overcome the influence of such highly performing publications.

Since standardization might be heavily influenced by the presence outliers, data have been winsorized to the 99th percentile. This means that the instances in which the number of forward citations is higher than the 99th percentile have been replaced with such latter value. This same operation is is also performed by Squicciarini (2013) before building patent quality indicators.

The countries selected or this comparison are the ones that filed the highest number of patents in EV-related technologies, namely USA, Japan and Germany. They will constitute a group of “benchmark contries” that will allow me to draw conclusion on the relative performance of Chinese patents.

5.4 Considerations on chosen indicators

5.4.1 Family size

As explained above, patent applicants can see their right be extended in other countries. A patent family is the collection of applications regarding the same patent, filed in multiple jurisdictions. In fact, from the Paris Convention in 1883, patent applicants have 12 months from their first patent application to claim priority on the same patent in another jurisdiction. It is reasonable to assume a correlation between the value of an invention and the degree of expansion that its owner is aiming to reach. Based on this reasoning, Putnam (1997) argues that family size is a meaningful indicator to measure the value of a patent, as it resulted in being correlated with the survival time span of a patent. This argument is also consistent with the results obtained by Harhoff et al. (2003), who verified that highly cited patents are also more likely to be internationally broad.

One limitation of family size as an indicator of patent quality is the fact that European patent have a greater probability to have a large family, since filing at the EPO allows to easily seek patent protection in multiple European countries. Moreover, since it takes time for a patent to be published, family size in more recent years might be influenced by timeliness. Keeping such limitations in mind, family size is still a commonly used indicator for patent quality (Squicciarini et al. 2013).

Backward and forward citations are other widely accepted indicators for measuring the value of a patent. Forward citations are defined as the citations that a patent received from other patent publications. Backward citations are the other side of the story: the citations that a certain patent does towards other patents. Citations, as explained in the previous section, are defined in the search phase of the patent application procedure.

5.4.2 Foward citations

Counting received citations as a method for evaluating patent quality is actually very similar to what is done in the academic literature to identify the most influential publications. The more a patent is cited by subsequent publications, the more evident the influence of its contribution (Harhoff et al., 2003). Trajtenberg (1990) introduces the idea of weighting SPC with the number of citations a patent has received in order to obtain a proxy of the value of a patent. He empirically demonstrates that such indicator is able to capture the economic value of a patent, as highly cited patents resulted in being highly correlated with independent measures of social gains. This view reflects the evolution of innovation as an incremental process. Crucial intellectual property is likely to have an influence on subsequent patents and that build knowledge on top of it. The number of forwards citations as a reliable measure of patent quality finds a number of empirical confirmations in the literature, as it generally positively correlates with patent value (Harhoff et al., 1999; Harhoff et al., 2003).

5.4.3 Backward citations

Backward citations are a measure of patent quality as they capture how broad a patent is. In fact, a high number of citations pointing at other patents, especially in other technological fields, indicates that the patent draws knowledge from a variety of fields. Also for this indicator, empirical findings show its positive correlation with patent value (Harhoff et. al, 2003).

6. Results

In this section I will be addressing the research question from an empirical perspective. Firstly, at this point, it is relevant to define measures of technological upper hand. In order to analyse the technological knowledge stock of Chinese and benchmark foreign companies, I referred to patent quality analysis.

6.1 Patent quality: family size

I start with this because it is one of the most basic and static indicators of patent quality of a country. For this reason, it constitutes a meaningful starting point for my analysis.

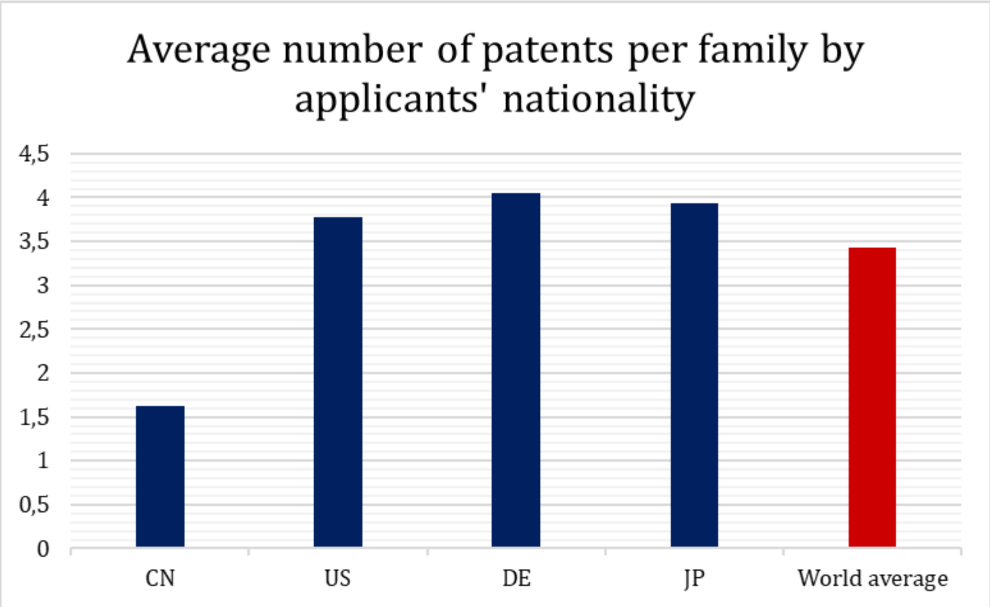

Figure 7. Average number of patents per family

Figure 7 displays how many patents belong to the same patent family in the sample, on average. The way the graph has been built does not take into account fractional counting, therefore it does not rely on the number of families rather on the number of patent applications. For the purpose of this initial overview on family size, this is not an issue. As it is evident from the bar chart, China lags behind the benchmark countries and the world average when it comes to family size. This means that the countries in which Chinese applicants sought intellectual protection were few (less than one, besides the country the patent was initially filed in). Applicants might be willing to incur in higher cost for filing their most valuable patents to extend their protection internationally. Since the value of patents is therefore also associated with their geographical scope, it is reasonable to expect that Chinese patents have a lower quality compared to the rest of the world's.

6.2 Patent quality: Forward citations

Below is displayed the regression of the standardized score for forward citations, *citing_std*, on the "age" of the patent, represented by *timefromgrant*, which was obtained as 2014 (the latest year in the dataset) minus the earliest publication year of the patent.

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
China		-0.676*** (0.00677)	-0.577*** (0.00966)	-0.252*** (0.0118)
Germany				-0.106*** (0.0171)
USA				0.823*** (0.0218)
Japan				0.376*** (0.0149)
chinatime			-0.0288*** (0.00118)	-0.0248*** (0.00147)
gertime				0.0101*** (0.00189)
ustime				-0.0154*** (0.00207)
japtime				0.0107*** (0.00161)
timefromgrant	1.93e-09 (0.000626)	-0.0134*** (0.000673)	-0.0105*** (0.000741)	-0.0145*** (0.00115)
Constant	1.000*** (0.00565)	1.226*** (0.00711)	1.209*** (0.00747)	0.884*** (0.0101)
Observations	147,469	147,469	147,469	147,469
R-squared	0.000	0.039	0.040	0.081

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 1. Linear regressions of standardized forward citations over the age of the patent and country effects

The first model shows that no time trend is detected, therefore the standardization by yearly mean works.

My aim is verifying whether the number of forward citations to Chinese patents has increased over time and comparing this trend to benchmark countries that have been traditionally competitive internationally in the automotive industry.

Firstly, Model 2 shows that Chinese patents consistently receive fewer forward citations with respect to the rest of the sample. China is a dummy variable that takes value 1 when the patent had been filed by a Chinese company and 0 otherwise. This result makes sense, since the electric mobility technologies in China have been developed relatively late, compared to benchmark countries, like Japan, the US and Germany. In absolute terms, Chinese patents have a lower quality compared to non-Chinese patents. This result is consistent with what was shown looking at average family size. Now, the aim is verifying whether the quality of Chinese patents has increased over time. This can be done looking at the interaction between the China and the age of the patent in Model 3. This interaction is represented by the variable *chinatime,* obtained multiplying the value of *China* by *timefromgrant.*

Here the interpretation of the model. Even though China does receive fewer citations than non-Chinese patents overall, the relationship between the number of forward citations and the age of the patent is inverse: this means that older patents (higher timefromgrant), receive less citations, while newer patents (lower timefromgrant) receive more. This can be interpreted as Chinese patents actually improving in quality over time.

Timefromgrant shows the general tendency of the whole sample. Note that even though data have been standardized, model 3 shows that there is actually a general negative relationship between age and forward citations. This apparently non-intuitive result is caused by two effects: the higher number of Chinese patents being filed over time, and the higher number of forward citations they receive. For this reason, at some point the relationship between age and forwards citations becomes “dominated” by the behaviour of Chinese patents. This explains the appearance of a time trend when China is included in the regression. For the sake of this analysis, this fact does not invalidate the relevance of the results, as long as the interaction factor *chinatime* is compared with the same indicator built for the benchmark countries. Moreover, a robustness check displayed in the following section of this chapter clearly illustrates both the general trend of the data and the countertendency followed by China.

To show that the quality of Chinese patents is increasing, a comparison with "benchmark countries" offers a deeper insight on the point. For each of the countries both the dummy variable and its interaction with *timefromgrant* have been created.

Model 4 shows that the countries that consistently receive more citations are the US and Japan, while Germany lags behind on technological knowhow in this sense. The interaction terms reveal that China and the US follow the same tendency: a general improvement in the quality of their patents. Instead, latest Japanese and German patents have fewer citations compared to the past. Therefore, in general, US appears to outperform all the other countries: its patents are of higher quality in absolute terms and keep on improving over time. Japanese patents have received a high number of forward citations, but this trend is slowing down. It appears that German patents are likely to be outperformed by Chinese ones in the long term: both countries receive a low number of citations, but China is actually growing in that respect, while Germany shows that patents in the past were more cited than recent ones.
Plotting the trends of forward citations for the countries taken into consideration is an effective way to visualize the catching-up of China over the benchmark countries.

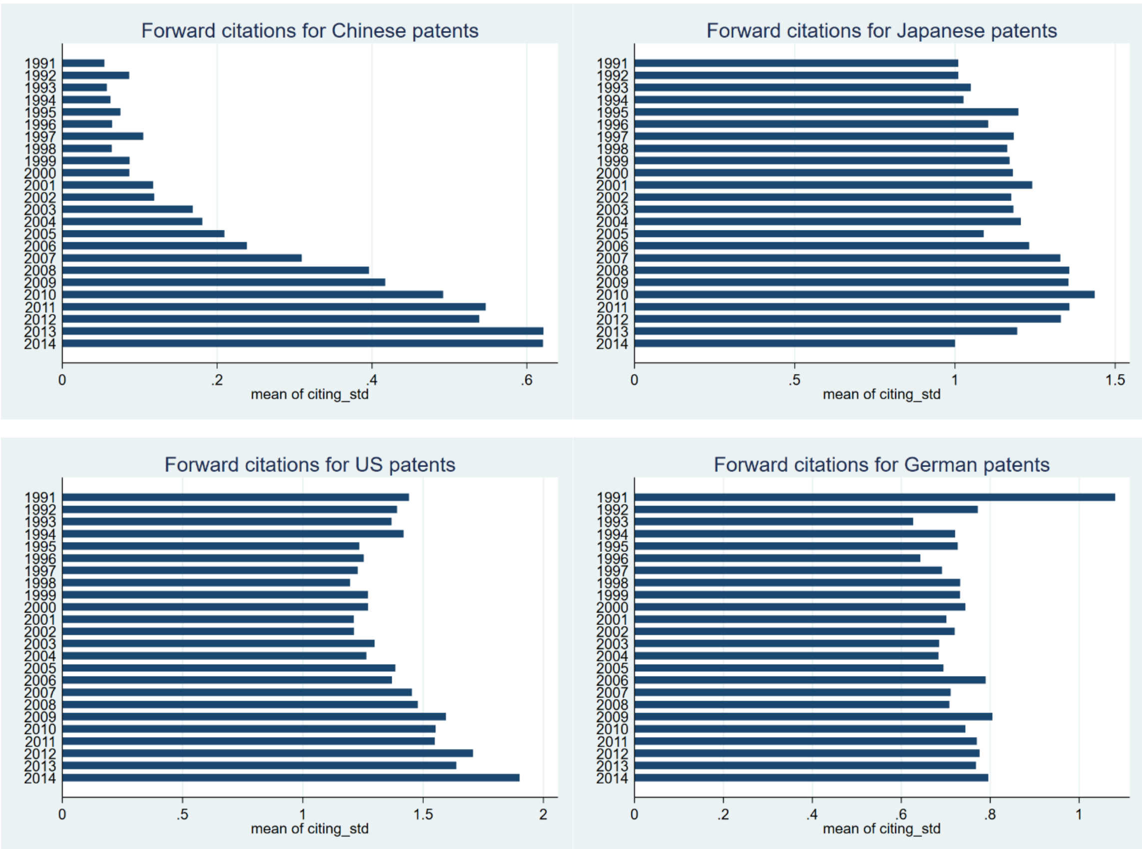

Figure 8. Forward citations on selected countries' patents including time interaction

In general, even though the standardized score of forward citations for Chinese patents is still below the one of the benchmark countries, there is a clear growing trend in the quality of Chinese patents over time. The four countries follow different behaviours when it comes to patent quality, as displayed in Table 2 on the basis of two dimensions: static number of citations at the moment, and tendency followed over time.

	Number of forward citations is decreasing	*Number of forward citations is increasing*
Receives high number of citations	Japan	USA
Receives a low number of citations	Germany	China

Table 2. How China and benchmark countries compare in terms of static and dynamic measures

It is therefore evident that China is catching up in the field of electric vehicles. It still lags behind other countries, as the static measure shows, but is currently increasing the quality of its know-how.

6.3 Patent quality: backward citations

The way backward citations were studied is identical to the one followed for forward citations. Below the regression of backward citation on China and the benchmark countries with interactions.

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
China		-0.963***	-0.881***	-0.516***
		(0.00528)	(0.00704)	(0.00887)
Germany				0.0152
				(0.0138)
USA				0.972***
				(0.0193)
Japan				0.325***
				(0.0114)
chinatime			-0.0239***	-0.0287***
			(0.000896)	(0.00116)
gertime				0.00713***

				(0.00163)
ustime				-0.0202***
				(0.00193)
japtime				-0.0140***
				(0.00129)
timefromgrant	-1.39e-09	-0.0191***	-0.0167***	-0.0119***
	(0.000583)	(0.000610)	(0.000675)	(0.00101)
Constant	1.000***	1.323***	1.308***	0.942***
	(0.00486)	(0.00611)	(0.00642)	(0.00839)
Observations	147,469	147,469	147,469	147,469
R-squared	0.000	0.090	0.090	0.148

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3. Linear regressions of standardized forward citations over the age of the patent and country effects

The models show that Chinese patents do not generally to cite other patens, but this tendency has actually changed over time. This might mean that Chinese applicants are drawing more knowledge for foreigners, or alternatively that Chinese patents are becoming broader. The number of backward citations is recognized as another indicator of patent quality; therefore, it supports the trends shown when analysing forward citations.

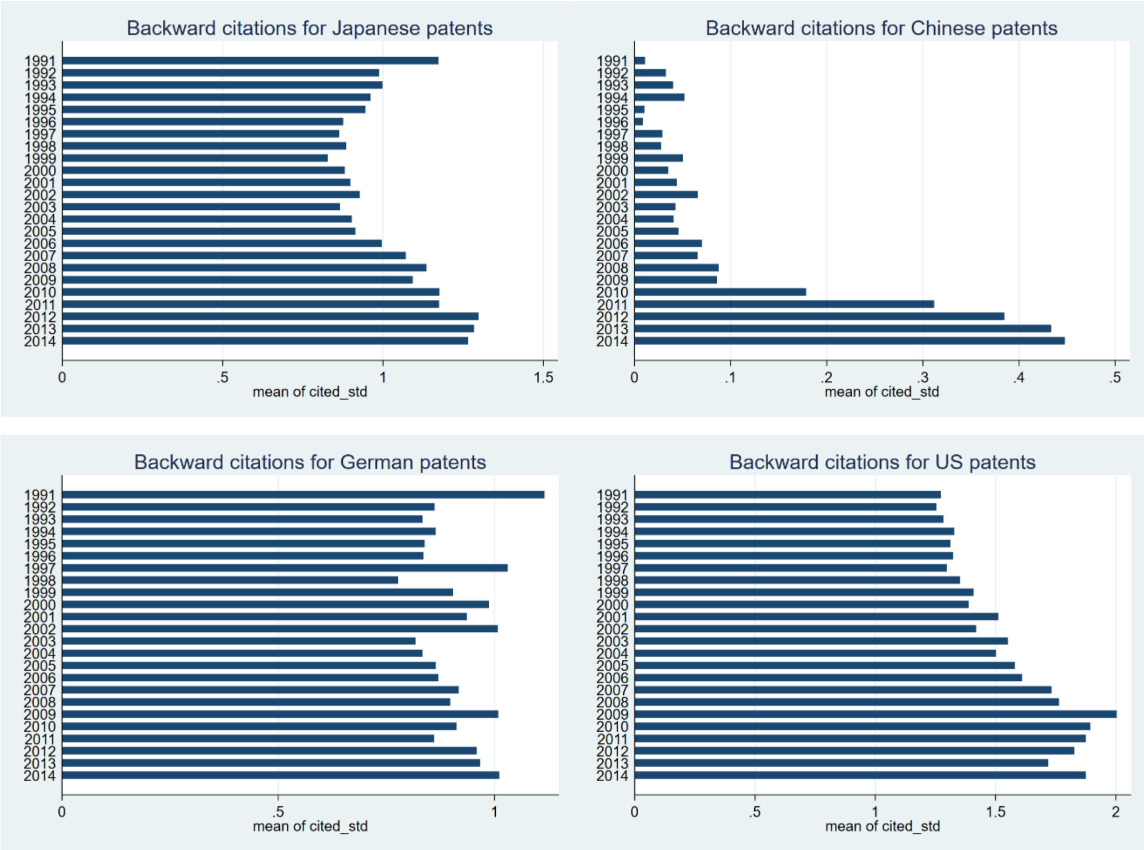

Figure 8. Backward citations on selected countries' patents including time interaction

The trends followed by Japan and the US have a more positive tendency compared to the same graph depicted for forward citations. Nevertheless, China still shows a steep growth in the number of cited patents.

6.4 Robustness checks

In order to assure the validity of the results obtained in the previous section, rubustness checks are needed. In particular, since introducing China causes the appearance of a time trend, the first robustness check will be dedicated to showing that an alternative approach leaves the result unchanged.

VARIABLES	(1) Model 1
China	-0.368***
	(0.00704)
chinatime	-0.104***
	(0.00157)
1992.earliest_publn_year	-0.0185
	(0.0735)
1993.earliest_publn_year	0.102
	(0.0716)
1994.earliest_publn_year	0.147**
	(0.0716)
1995.earliest_publn_year	0.137*
	(0.0701)
1996.earliest_publn_year	0.150**
	(0.0690)
1997.earliest_publn_year	0.109
	(0.0683)
1998.earliest_publn_year	0.0953
	(0.0676)
1999.earliest_publn_year	0.0454
	(0.0676)
2000.earliest_publn_year	0.0254
	(0.0673)
2001.earliest_publn_year	0.0414
	(0.0660)
2002.earliest_publn_year	0.0296
	(0.0655)
2003.earliest_publn_year	-0.0539
	(0.0654)
2004.earliest_publn_year	-0.127*
	(0.0649)
2005.earliest_publn_year	-0.216***
	(0.0645)
2006.earliest_publn_year	-0.334***
	(0.0643)
2007.earliest_publn_year	-0.437***
	(0.0641)
2008.earliest_publn_year	-0.434***
	(0.0638)

2009.earliest_publn_year	-0.570***
	(0.0638)
2010.earliest_publn_year	-0.661***
	(0.0637)
2011.earliest_publn_year	-0.826***
	(0.0637)
2012.earliest_publn_year	-1.100***
	(0.0635)
2013.earliest_publn_year	-1.418***
	(0.0635)
2014.earliest_publn_year	-1.822***
	(0.0635)
Constant	2.678***
	(0.0631)
Observations	146,541
R-squared	0.353

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Normal behaviour of forward citations in the sample

The regression in Table 4 shows the general tendency that forward citations follow in the whole sample before the standardization. Earlier patents receive a higher number of citations, while they inevitably decrease in more recent years. At the same time, China and *chinatime* maintain the same signs as above: China indicates lower citations in absolute terms, but *chinatime* highlights how the country is in countertendency with respect to the rest of the sample (younger patents receive more citations).

In order to be able to interpret the results correctly, multicollinearity has to be ruled out. Table 5 presents the multicollinearity test for Model 4 in the regression for forward citations and for backward citations.

Variable	*VIF*	*1/VIF*
ustime	4.88	0.204977
timefromgrant	4.77	0.209478
japtime	4.49	0.222579
USA	3.6	0.277729
Japan	3.52	0.283753
gertime	3.16	0.316528
China	3.13	0.31948
Germany	2.82	0.355157
chinatime	2.42	0.412959
Mean VIF	3.64	

Table 5. Multicollinearity test for regression on forward citations

Since the Variance Inflation Factors, that measure the amount of inflation in the variance of the estimated regressions, assume moderate values, the model of the overall regressions are acceptable.

6.5 Identification of leading Chinese entities

The result from the previous section shows that Chinese entities do not exhibit high-value patents, but also that this trend is gradually changing, and that Chinese entities have acquired more relevance over time.

The aim of this section is identifying the profile of the companies or other entities that are likely to lead the trajectory of technological catching up. The procedure is going to be carried out by looking at a set of statistics both on patenting frequency and quality of the filed patents for the most frequent patentors, in the spirit of Thoma (2013). In particular, the standardized score of forward citations has been selected as a synthetic measure of patent quality in this section. Be reminded that the indicator is equal to 1 if the number of forward citations for the patent is equal to the yearly average. Therefore, anything greater than 1 is an above-average-quality patent.

Since international expansion is involved in the catching up process (Malerba et al., 2011), the mentioned indicators will be first computed for the whole sample of Chinese companies (individuals excluded), and then for the patent applications filed in a patent office different from SIPO. Contrasting these two results will give a proxy of the strategies that Chinese companies are putting into practice in the field. Moreover, another aspect that is going to be taken into account is the ownership type of the company, or in other words whether it is a SOE or a POE. This is relevant since in the history of the development of the sector, SOEs received more favourable treatment through governmental policies, compared POEs.

After analysing the quality of Chinese patentors overall, the analysis goes more in depth, considering only the technologies China is mostly competitive in. In this cohort of key-technologies, the most frequent patentors will be laid out. This gives a proxy of the key contributors to the core technological classes related to EV-production.

A cross comparison of the produced statistics will provide a picture of the entities that are the most involved in knowledge generation in EV-related technologies and their intentions in terms of technological expansion.

Company	*Patent quality*	*Type*
JIANGSU ELECTRIC POWER	3.31	COMPANY (SOE)
CHINA ELECTRIC POWER RESEARCH INSTITUTE	3.12	GOV NON-PROFIT
BYD	1.45	COMPANY (POE)
CHINA SOUTH POWER GRID ELECTRIC POWER RESEARCH INSTITUTE	0.99	COMPANY (SOE)
NARI TECHNOLOGY	0.98	COMPANY (POE)
EAST CHINA ELECTRIC POWER RESEARCH INSTITUTE	0.97	GOV NON-PROFIT
BEIJING SIFANG AUTOMATION	0.88	COMPANY (POE)
CHONGQING CHANGAN AUTOMOBILE	0.77	COMPANY (SOE)
ZTE	0.76	COMPANY (POE)
HUAWEI TECHNOLOGIES	0.67	COMPANY (POE)
NANJING NARI-RELAYS ENGINEERING TECHNOLOGY	0.66	COMPANY (POE)
SGCC (STATE GRID CORPORATION OF CHINA)	0.63	COMPANY (SOE)
ZHEJIANG GEELY AUTOMOBILE RESEARCH INSTITUTE	0.61	COMPANY (POE)
C-EPRI SCIENCE & TECHNOLOGY	0.60	COMPANY (SOE)
HONGFUJIN PRECISION INDUSTRY (SHENZHEN)	0.41	COMPANY (POE)
HAIER GROUP	0.33	COMPANY (POE)
OCEAN'S KING LIGHTING SCIENCE & TECHNOLOGY	0.27	COMPANY (POE)

Table 6. Patent quality of the most frequent Chinese patentors

Table 6 displays the companies that have patented both abroad and at SIPO and that have filed more than 50 patents in the time-window 1991-2014. It is interesting to notice that State Owned companies (SOEs) perform well in terms of patent quality, as their standardized score is always around or above 1. Additionally, the two outperformers of the cohort, namely China Electric Power Research Institute and Jiangsu Electric Power are both state-owned.

Company	*Patent count*	*Patent quality*	*Type*

HUIZHOU KIMREE TECHNOLOGY CO., LTD., SHENZHEN BRANCH	5	4.98	COMPANY (POE)
BYD	33	1.94	COMPANY (POE)
HUAWEI DEVICE	5	1.70	COMPANY (POE)
CHENGDU MONOLITHIC POWER SYSTEMS	4	1.69	COMPANY (POE)
DELTA ELECTRONIC ENTERPRISE MANAGEMENT (SHANGHAI)CO.	4	1.59	COMPANY (POE)
GOGORO	5	1.53	COMPANY (POE)
HUAWEI TECHNOLOGIES	3	0.93	COMPANY (POE)
FU TAI HUA INDUSTRY (SHENZHEN)	7	0.41	COMPANY (POE)
HONGFUJIN PRECISION INDUSTRY (SHENZHEN)	84	0.39	COMPANY (POE)
SHENZHEN FUTAIHONG PRECISION INDUSTRY	10	0.37	COMPANY (POE)
INNOCOM TECHNOLOGY (SHENZHEN)	6	0.29	COMPANY (POE)

Table 7. Patent frequency and patent quality for Chinese companies patenting outside of SIPO

In Table 7 patent count has been kept in order to show that a high score in patent quality might still be not representative of the performance of the entity, since it might be associated with a low patent count. Moreover, the patent count partly confirms what was found looking at patent family size: Chinese companies tend not to patent a lot abroad. Indeed, only two companies in the whole sample have filed more than 10 patent applications in the time-window 1991-2014, and those are BYD and Hongfujin Precision Industry (Shenzhen). Additionally, all the patentors abroad are POEs. This reveals that SOEs do not seek geographical expansion and that are therefore not interested in having patent protection abroad.

Now the analysis will consider only the key technological classes and plot the companies that patent the most in those. In order to identify the technological classes to which the most cited Chinese patents belong to, only the observations in the 95th percentile have been selected for China. This means that only the highest quality Chinese patents have been kept. Afterwards, the count of those high-quality patents for each technological class has been carried out. Chinese companies can be classified as having a technological upper hand in those technological classes in which they have the highest absolute frequency of high-quality patents. According to the data, China is catching up in core areas regarding both EV-related technologies (batteries and energy storage) and energy generation from renewable sources.

Narrowing down the focus on the Chinese companies that patent in these technologies, BYD is by far the leader in the cohort, followed by two SOEs and Gogoro, a VC-backed company that operates in the e-scooter business.

Company	*Patent count*	*Type*
BYD	363	COMPANY (POE)
CHINA ELECTRIC POWER RESEARCH INSTITUTE	92	GOV NON-PROFIT
SGCC(STATE GRID CORPORATION OF CHINA)	77	COMPANY (SOE)
GOGORO	60	COMPANY (POE)
CHINA SOUTH POWER GRID ELECTRIC POWER RESEARCH INSTITUTE	34	COMPANY (SOE)
DELTA ELECTRONIC ENTERPRISE MANAGEMENT (SHANGHAI)CO.	28	COMPANY (POE)
GUANGDONG OPPO MOBILE TELECOMMUNICATIONS	28	COMPANY (POE)
HUAWEI TECHNOLOGIES	27	COMPANY (POE)
TRANSTAR GROUP	22	COMPANY (POE)
TSINGHUA UNIVERSY	21	UNIVERSITY
HUIZHOU KIMREE TECHNOLOGY CO., LTD., SHENZHEN BRANCH	20	COMPANY (POE)
BEJING DIANBA TECHNOLOGY	19	COMPANY (POE)
CHANGCHUN RAILWAY VEHICLES	19	COMPANY (SOE)
CHENGDU MONOLITHIC POWER SYSTEMS	18	COMPANY (POE)
SAIC MOTOR	18	COMPANY (SOE)

Table 8. Chinese companies patenting the most in lead technological classes

Overall, the cross-comparison of most frequent and highest quality patentors in the above different instances has laid out some definite trends. Firstly, there is a clear distinction between companies that generally file high-quality patents and firms that instead seek geographical expansion. This result is consistent to what found looking at Chinese patent family size: Chinese entities tend not to file abroad. One exception to this general trend is represented by BYD, that instead presents high quality patents and files a relatively high amounts of patents abroad.

Moreover, there is no significant difference between the quality of the patents filed by SOEs and POEs. However, POEs are the entities that generally seek geographical expansion. This might be due to the high bar of competition set by the presence of SOEs in the Chinese market. An additional internesting insight is that Chinese companies focus on a well-defined set of technological classes. This emerges looking at the list of most frequent patentors overall and the most frequent patentors in the core-technologies, as the two sets of entities are comparably similar.

7. Discussion and Conclusion

This work was concerned with assessing and characterizing the process of China catching up in EV-related technologies. The phenomenon has been first evaluated from a qualitative perspective, detecting the trends identified by the literature on catching up. It emerged that access to foreign knowledge and active government policies introducing a heavy focus on R&D on the development of indigenous innovation were two elements that had proven consistency in the history of the development of the Chinese automotive industry. This overall is in harmony with the tendencies depicted in the catching up literature: knowhow firstly comes from external sources, such as foreign sources of knowhow. Subsequently, in order to catch up, the developing country needs to nurture absorptive capacities to adapt those technologies to its own market. Those are sprung through R&D efforts and attempts to build indigenous capabilities.

Given the above landscape, this thesis wanted to answer the question “Is China catching up in EV-related technologies?” using an analytical approach. Taking patents as a proxy of national innovativeness, this work examined the general state of Chinese knowhow in EV-related technologies, which still appears to be below leading countries. However, a dynamic analysis based on the study of the interaction term between nationality and age of a patent shows that the quality of Chinese patents in this field is increasing. Further characterizing this result, it emerges that the Chinese entities that patent the most frequently in this field are companies, with a comparable share between SOEs and POEs for what concerns national borders. International expansion does not seem a priority for the majority of the companies in the cohort. Instead, Chinese companies appear to be focusing on producing patents of increasing quality within national borders and in a specific set of core technologies regarding EVs. Coherently with what stated by Malerba et al. (2011), Chinese companies are currently leveraging the dimensions of the national market in order to strengthen their position.

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