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The Relationship Between Industrial Manufacturing Innovation and CO2 Emissions in China: Evidence from Provincial Level Patent Data, 1999-2009

Abstract

The beginning of the 21st century marked a time in which the economic and environmental landscape in China was changing very rapidly. The manufacturing industry was facing up to rising factor costs, the rise of profit-oriented private enterprises was eminent, and the pro-growth strategy of the economy was causing increasing environmental degradation. In particular, China was fast becoming the largest emitter of CO_2 emissions globally. As China seeks to utilize innovation as the key to a more sustainable growth strategy, as well as try to reach its emissions abatement targets in the future, analysing the effect that innovation has on the environment will prove ever more important for policy makers going forward. That is why this paper set out to explore the relationship between innovations in the manufacturing sector and CO_2 emission levels during this critical era of change between 1999-2009 that played host to the initial wave of profit-oriented private firms. By using provincial level patent data as a proxy for innovation, this study included all technological innovations in the analysis, recognizing that all innovations have the capacity to either directly or indirectly induce a change in CO_2 emissions. The key findings are that environmental technology patents have a negative relationship with emissions, and that some non-green technologies also possess a relationship with emissions. Specifically, chemicals patents were shown to have a positive effect on emissions, and electronics patents lagged by 1 year were shown to negatively affect emissions.

Keywords: Patents, Innovation, CO2 Emissions, China, Panel Data

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1 | Introduction

During the final two decades of the 20th century, China experienced profound levels of economic growth. Harnessing its abundance of cheap labour by specialising in heavy industry as its growth strategy, the nation recovered from its lows as a socialist economy battling mass starvation to an economy brimming with growth and development by the end of the 1990s (Lin, 2012). Through a gradual series of reforms during this period, the Chinese Communist Party allowed free market mechanisms to take charge resulting in the emergence of a low-cost manufacturing industry that exported globally. Exports more than quintupled between 1992 and 2007 helped by the fact that local governments offered preferential treatment to these industries in line with their pro-growth priorities (Jarreau & Poncet, 2012). However, due to this pro-growth strategy, carbon dioxide emissions (CO_2) have skyrocketed in China. Following entry to the WTO in 2001 which further expanded the manufacturing industry, they became the world's largest energy consumer and emitter (Shan et al., 2018). Environmental concerns were put aside so that Chinese industries could keep costs at a minimum and remain competitive on the global market. This strategy eventually changed when the 11th 5-Year Plan was announced in 2006 which set out goals to "promote development by relying on resource conservation and environmental protection" and to "build a…low input, high output, low consumption and emission" based economy (NDRC, 2006). It is the intent of this paper to contribute to the discussion of a sustainable and environmentally friendly growth model in China by analysing the effect that technological innovation has had on emissions during the period 1999-2009, which could then shape future industrial policies geared towards curbing pollutant industries.

This period also saw the dramatic rise of profit-maximizing private-owned enterprises. Faced with unclear property rights and productivity issues rooted in inefficient incentive mechanisms, managers of township and village enterprises (TVEs) battled with local government officials for more secure institutional arrangements in the late 1990s. This began the privatization movement which grew even faster following formal recognition of private property rights in 2004 (Wang, 2010). There are two scenarios that can emerge with regards to profit-oriented private manufacturing firms and their stance on CO_2 emissions. One is that these firms may seek to harness the potential cost saving benefits of energy efficient technologies in the production line (Andersson et al., 2018). The other is that these firms may exploit China's weak and poorly enforced environmental institutions by operating emission intensive technologies and ignoring environmentally friendly practises with the aim of keeping costs at a minimum (Andersson et al., 2018). Given the rapid growth of invention patent applications during this period, one can assume that many manufacturing firms took the former approach in seeking to utilize new technologies that would reduce both operating costs and CO_2 emissions (NBS, 2019). It is the intent of this paper to analyse the effect of innovation on CO_2 emissions by using patent filings between 1999-2009 as a measure of innovation.

Moving on from this period and into the 2010s, the low hanging fruits of growth from China's initial wave of manufacturing had all been picked and marginal returns to capital had decreased substantially leading to the central government's numerous announcements in recent years outlining innovation as the key to sustainable economic growth in the future. This structural change in China's development model towards innovation can be seen in the growth of patents filings which have increased by nearly 530% since 2008 (WIPO, 2019). Given this push for innovation alongside China's emissions reduction targets, it is necessary to investigate what types of innovations have led to the greatest emission abatements within manufacturing industries during this initial period of profit-maximizing private firm activity.

Specifically, this paper will look at the relationship between the growth in patents applications and emissions in the following manufacturing categories: Environmental Technology, Chemicals, Electronics, and Other Manufacturing. This may shed light on what types of innovations the Chinese government may wish to focus on in the future as they continue to strive towards lower greenhouse gas emissions (GHG) and a more sustainable economic development.

The remainder of this thesis will be structured as follows: In the following section, a theoretical framework will be established and the hypotheses for the analysis will be outlined. Following this, a more detailed look into the Chinese context will be examined in section 3, paying respect to the rise of the manufacturing industry and its relationship with the environment. Data and methodology will follow in the empirical analysis section, allowing for a description and insight into the data and models being used. The results from the analysis will then be presented in the next section followed up by a concluding section for a final discussion of the analysis.

2 | Theoretical Framework

Technology will likely play a big role in the discussion of emissions abatement in the future. This section will analyse the relationship between growth and emissions and then explore the avenues with which innovation can affect emissions. Specifically, the concept of direct and indirect effects that innovations can have on emissions will be discussed as well as why patents are a reliable measure of innovation. Following this, three hypotheses will be outlined which will establish the objectives for the analysis.

2.1 | Innovation, Patents, and Emissions

It has been widely shown that there exists a relationship between economic growth and emissions (Brock & Taylor, 2004). For developing economies, the transition from an agrarian based economy to the production of heavy-industry pollutant goods usually results in environmental degradation. However, as these economics continue to grow, the marginal returns from heavy-industry production begin to dwindle which then leads to another transition into more high-tech and service-based industries. It is during this transition that innovation becomes a key component in the relationship between economic growth and the environment because the use of high technologies which increases the efficiency of production can result in lower emissions. The environmental Kuznets curve (EKC) describes this inverted U-shaped effect that economic growth has on the environment. The concept is such that as an economy initially begins to develop, the rapid pace of industrialization will have a negative effect on the environment; but after a certain point of development, the population and the government will become more concerned about the environment and will begin to adopt more environmentally friendly processes (Grossman & Kreuger, 1995). Due to the lack of knowledge and resources in developing countries, it is generally developed economies that will engage in innovation. Hence, according to the EKC theory, there should exists a negative relationship between innovation and emissions in these economies.

Many studies have already looked at the relationship between innovation and emissions. It is widely agreed upon that increased investment in R&D can reduce emissions (Fernandez et al., 2018). Garrone & Grilli (2010) showed that there is a positive link between expenditure in R&D and energy efficiency, and Bernstein et al. (2006) showed that there is potential for reducing emissions when accounting for the embodiment of new technologies in a firm's production function. It has also been shown that CO_2 emissions are negatively related to research intensity, distance to the technological frontier, and the absorptive capacity of the economy to harness foreign technologies especially in high-energy consuming intensity sectors (Ang, 2009; Teng, 2012). Other past research on the matter has focused on a specific form of innovation, namely 'eco-innovation' which serves to reduce environmental risk, pollution, and other negative impacts of resources used (Lee & Min, 2015; Cai & Zhou, 2014). For example, Lee and Min (2015) looked at Japanese manufacturing firms between 2001 and 2010, finding a negative relationship between eco-innovation and emissions which also resulted in increased financial performance.

At the firm level, the motivation to invest in eco-innovation is driven by both internal and external factors. Included in a firm's internal factors are its technological and organizational capabilities such as physical ability and capital stock of knowledge, whereas external factors would be pressure from environmental regulators and green demands from consumers (Cai & Zhou, 2014). Popp (2002) contributed to this discussion by showing that energy prices are also a factor that drives firm level eco-innovation, whereby firms are induced to innovate in energy efficient technologies because of increasing relative factor prices. Traditionally it was thought that investing in environmentally friendly processes would increase costs (Lee & Min, 2015). However, a more recent perspective is that there are long run financial returns up for grabs given early mover investment in environmental technologies, in particular within the manufacturing sector where firms develop green products or processes to increase operational and energy efficiency (Dangelico & Pujari, 2010). For example, Long et al. (2017) showed that environmental innovation has a positive effect on environmental performance, which decreases costs for raw materials and waste disposal through cleaner production, in turn reducing carbon emissions. In line with these findings, Andersson et al. (2018) used Chinese provincial level data between 1992 and 2010 to show that private firms emit less carbon dioxide than state-owned firms because private firms are more profit-oriented and will thus seek to implement the most efficient technologies into the production process. In this view, a negative relationship between innovation and emissions should be stronger in a market comprised of profit-maximisers.

Patents will be used as a proxy for innovation in this study. Patents are often used as a proxy for innovation in economic analysis because they provide a reliable measure of innovative activity (Acts & Audretsch, 1989). Since it is possible to identify patents into specific technological classifications, it then leads to the possibility of being able to analyse the effect that these technologies have on energy efficiency and consequently emissions. Furthermore, using patent data makes it viable to identify patents into process and product innovations, which is a fundamental aspect given the aim of this study. Sorting patents into technological classifications means that it is possible to isolate the patents that represent a change to the production process, as opposed to a change or addition to the final product (Popp, 2001). General patent counts have been used to show that innovation plays a crucial role in reducing carbon emissions (Mensah et al.,2018). However, the drawback of using general patent counts is that one cannot establish what types of innovations have the greatest effect on emissions. Most other studies have generally focused on the effect that green patents have on emissions. For example, Wurlod and Noailly (2018) used data on green patents among 17 OECD countries between 1975 and 2005 to find that a 1% increase in green patenting contributed to a 0.03% decline in energy intensity. Popp (2001) used energy patent data to create stocks of energy-efficient knowledge which could then be added to firm cost functions and showed that one third of the change in energy consumption among 13 industries were from induced innovation. On a similar note, Popp (2002) used U.S patent data between 1970-1994 to show that energy prices have a strongly significant positive effect on innovation. Hence, as a result of external factors such as energy prices, induced innovation of energy technology patents has been shown to reduce emissions intensity.

Before continuing, it is important to note that patents are not a fully optimal measure of innovation, so one must recognize its drawbacks. Firstly, it is difficult to establish the length of time between a patent application and the actual adoption of that new technology. Secondly, one cannot be certain that the province where a patent was submitted will also become the province where that innovation will be adopted. Thirdly, there exists significant variation in the quality of patents when measuring its effects since some filed patents are highly valuable and some have no commercial value. Moreover, the propensity to file a patent can vary across industry (Popp, 2001). Some industries choose to widely patent their inventions for protection against intellectual theft, whereas some industries recognize that secrecy of a new invention is more important, since the cost of revealing the invention to its competitors outweighs the benefit of patent protection (Popp, 2001; Ang, Yingmei, & Chaopeng, 2014). Thus, the results of an analysis using patents will showcase the effect of an average patent rather than any specific technological innovation.

Nonetheless, since the key internal motivation for innovating within the manufacturing sector is a goal of greater efficiency, patent data can still be used to show the effects that these endeavours have on productivity, financial performance, and the environment. Popp (2003) used patent data to link innovative activity to lower operating costs within coal-fired electric power plants, finding that a single patent provided $6 million in cost savings across the industry thanks to lower environmental regulation compliance costs. In this view, using patent data can show that both green and non-green technological innovations aimed at cost reductions and efficiency can lead to better environmental performance and ultimately lower carbon emissions.

Most studies, however, focus solely on green technologies, innovations directly aimed at emissions abatement and increased energy efficiency. Specifically, these environmental and green innovations are all new ideas which introduce efficient processes or apply new technologies with the sole aim of a reduction in environmental damage (Zhang et al., 2017). Chiou et al. (2011) classified green innovation into three types: green product innovation, green process innovation, and green managerial innovation; finding that product and process innovations positively affected environmental performance. However, it may not be just environmental technologies that result in a change in emissions. The accumulation of technological capabilities within a firm results in process innovations, which reduce the marginal costs of production, and product innovations, which expands the range of products available in the market (Fisher-Vanden & Sue Wing, 2008; Popp, 2001). Within the manufacturing sector, this leads to efficiency-improving and quality-enhancing innovations which have opposing influences on energy and emissions, where the former results in lowered emissions and the latter can lead to increased emissions (Fisher-Vanden & Sue Wing, 2008). Since, innovative processes lead to manufacturing firms being more energy efficient and less resource consuming, it can be implied that these innovations do not have to be specifically aimed at emissions abatement, rather any form of efficiency improving new technology can have an effect on carbon emission levels (Fernandez et al., 2018). Hence, all technological progress within the manufacturing sector as a result of profit maximizing firms facing internal and external factors can either directly or indirectly affect carbon emissions. The direct effects on emissions come from green technologies and the indirect effects come from non-green technologies, where the former is expected to have a smaller affect since eco-innovation does not generate any direct profits. With this in mind, this study will approach the relationship between patents and emissions from a different angle, by encompassing all patent classifications[1], not just energy or environmental technology patents

2.3 | Hypotheses Development

This study seeks to add to the literature on emissions abatement through technological innovation by recognizing that all process innovations have the capacity to either directly or indirectly effect emissions via energy efficiency improvements in the production process. Based on economic theory of profit-maximizing private enterprises as well as the literature on the relationship between innovation and emissions, I identify three hypotheses that may shed light on the particular types of innovations that have significantly affected carbon emissions in China.

Direct Emissions Abatement Innovations

It has been shown that profit-maximising firms will induce a change in the technological direction of innovations towards energy efficiency due to rising energy prices and to external factors such as stricter environmental regulations (Popp et al., 2010). Therefore, environmental innovation which aims to introduce new technologies and efficient processes with the goal of directly contributing to a reduction in environmental damage, is also sometimes a profit-maximising endeavour by private manufacturing enterprises (Zhang et al., 2017). Environmental technologies help to identify inefficiencies in the production process, particularly around resource consumption, and can thus directly improve energy efficiencies as well as help to reduce waste (Lee & Min, 2015). Previous studies have already identified a relationship between energy technology patents and reduced carbon emissions intensity in China; these patents being fossil-fuelled or carbon-free technologies aimed directly at reducing energy consumption (Wang et al., 2012a; Wang et al., 2012b). Since the time period under examination, 1999-2009, represents the initial wave of profit-oriented private enterprises in China, the environmental innovation and investment in green patenting that was taking place by these firms was largely motivated by cost and energy reductions in the production process, which will have subsequently led to a lower output of CO_2 emissions. In other words, the link between green innovation and emissions reduction may be stronger amongst profit-maximising private firms. Therefore, the first hypothesis is as follows:

[1] Patent categorized into 4 groups using 35 technology classifications. See WIPO (2008).

H1: Environmental technology patents have resulted in lower CO_2 emissions

Indirect Emissions Abatement Innovations

Not all innovations with the aim of greater efficiency in the production process are specifically environmental technology innovations. Manufacturing firms may innovate to improve the production process via more efficient use of resources or by introducing a new product which would expand the range of products available in the market. Both of these cases can lead to efficiency-improving or quality-enhancing innovations which can indirectly have opposing influences on energy and emissions. It is not hard to imagine, for example, a particular scenario where a firm invents a new technology which speeds up the manufacturing process of their products, but which also requires less energy to do so; thereby indirectly reducing carbon emissions. Innovative processes lead to new operations within the production line that are more energy efficient and less resource consuming, so it does not matter what the specific technological innovation is, since it can often result in less environmental damage; in particular less carbon emissions (Fernandez et al., 2018). Ang (2009) has showed that research intensity exerts both direct and indirect effects on carbon emissions. Therefore, since patents can be viewed as an output from R&D, and from the perspective of efficiency-enhancing innovations within the manufacturing sector, it may prove insightful to see which non-green technologies have contributed to changing emissions, especially as China seeks to reach its carbon emissions abatement goals set out in the Kyoto Protocol and Paris Agreement in recent years. Accordingly, the second hypothesis is as follows:

H2: Non-green technology patents have indirectly resulted in a change in CO_2 emissions

2.3.3 | Regional Differences

There exists significant heterogeneity across China due to geographical location, varying factor endowments, and economic factors such as industrial policies and infrastructural developments. Therefore, the attitude towards innovation and the capacity for emissions abatement will differ across the country. Hence, separating this vast country into smaller economic regions for the purpose of analysing the effect that innovation has had on the environment may lead to a better understanding of how to combine the government’s push for an innovation driven economy with their emissions abatement targets. For this reason, China's provinces[2] were grouped into three economic regions: Coastal, Intermediate, and Western (see table 1). SEZs and hi-tech industrial development parks were enacted in the coastal region throughout the 1980s and 1990s allowing foreign firms with more advanced technologies to locate here. Since these foreign firms were more engaged in technological innovation and because they created spillover effects to local domestic firms such as licencing contracts, the coastal region has accounted for the majority of patent applications (Cheung & Lin, 2004).

Table 1: Economic Regions

Eastern (Coastal) Region	Intermediate Region	Western Region
Beijing	Shanxi	Inner Mongolia
Tianjin	Jilin	Guangxi
Hebei	Heilongjiang	Chongqing
Liaoning	Anhui	Sichuan
Shanghai	Jiangxi	Guizhou
Jiangsu	Henan	Yunnan
Zhejiang	Hubei	Tibet
Fujian	Hunan	Shaanxi
Shandong		Gansu
Guangdong		Qinghai
Hainan		Ningxia
		Xinjiang

Source: National Bureau of Statistics China (NBS), Three Special Economic Regions

Although parts of northern and central China are home to heavy industry such as the iron and steel industry, it is the coastal region that has played host to the highest level of non-renewable energy consumption. This is because the coastal region has seen a rapid pace of urbanization and industrialization since 1978. As such, the demand for fossil-fuel energy has skyrocketed and will continue to do so as these developments extend into the future (Wang et al., 2012b). Lastly, the motivation for manufacturers to adhere to environmental regulations may differ across regions, especially in areas away from the eye of the regulator or, somewhat conversely, where local governments choose to turn a blind eye to bad polluting practises in favour of local economic growth, jobs, and taxes (Jiang et al., 2014). Therefore, the relationship between innovation and emissions may differ across China (Andersson et al., 2013). For this reason, the third hypothesis is hence:

[2] China's mainland has 31 provinces and municipalities excluding Taiwan, Hong Kong, and Macao.

H3: The relationship between patents and emissions are different across economic regions

3 | The Chinese Context

Establishing the relationship between direct and indirect effects of technological innovation on emissions in China may help to shape future industrial policies for a more environmentally friendly economic growth. The beginning of the 21st century in China was a unique period that played host to not only extreme levels of environmental degradation but also the first wave of a private firm dominated market engaging in innovation. This section will explain, on the back of a series of gradual economic reforms, how China arrived at this critical period in its development. Specifically, this section will start with a description of China's manufacturing industry, paying respect to the particular growth strategy implemented by the government to allow domestic manufacturers to modernize and remain competitive on the global market. The changing composition of ownership forms will then be discussed. Due to China's growth strategy, the issue of rapidly increased CO_2 emissions will be introduced and to close this section, China's strategy to combat environmentally and economically unsustainable growth in the form of innovation will be outlined, in particular the growth of patents during this period.

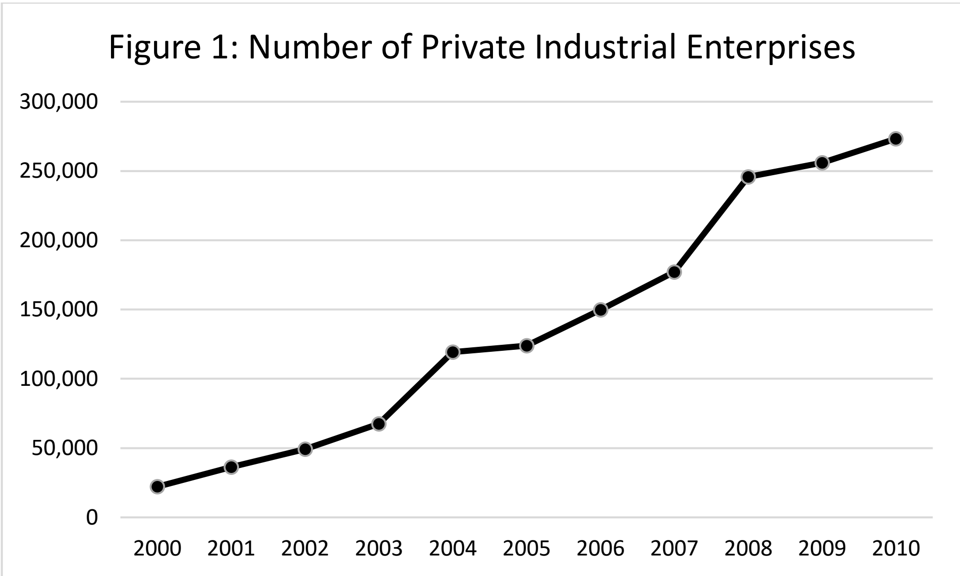
3.1 | China's Manufacturing Industry

Profit-oriented manufacturers will engage in innovation in the search for more efficient use of resources. Manufacturers in China at the beginning of the 21st century marked a new breed of industrial enterprise since, for the first time, the industry was mostly comprised of privately-owned profit-maximisers. Thus, they began to utilize innovation as a means of overcoming rising labour costs and greater competition from nearby east Asian neighbours. China's manufacturing industry was shaped by two decades of reforms and profound economic change which paved the way for the first-wave profit-oriented manufacturers to engage in innovation by the early 2000s. The introduction of these major economic reforms began in China in 1978 to try lift the state out of a stagnant and struggling centrally planned economic regime following the chairman Mao era. A household responsibility system (HRS) was first introduced allowing farmers to sell any produce over and above the state quota on the private market (Lin, 1987). Initial reforms like the HRS which tended in the way of a free market economy were merely official recognition by the CPC of what was already happening successfully at the local level in prior years. Following this, a fiscal contracting system was introduced in 1980 which allowed local governments to retain any excess revenues generated in their locality (Montinola, Qian & Weingast,1995. Several more incremental reforms during the subsequent years helped the general move away from a centrally planned towards a free-market economy.

Throughout the 1980s and 1990s the manufacturing industry in China was benefitting from low-cost labour which allowed the nation to become the key destination for foreign direct investment (FDI) and export processing plants, especially after foreign trade regulations were liberalised. Deng Xiaoping's 1992 tour of South China introduced the idea of a socialist market economy, which proposed a form of state capitalism where state-owned enterprises (SOEs) could exist in the private market. However, as the central government faced the growing concern of low productivity levels and high debt-to-asset ratios in SOEs, further reforms were implemented in the 1990s allowing state-owned firms (SOEs) to privatise (Baek, 2005)**.** Many SOEs were privatised following this new law which forwarded the growing emergence of a free market economy filled with profit-maximising firms. Wei and Tang (2017) have showed that the development of private ownership in China played an important part in firm performance and the growth of the manufacturing sector. Andersson et al. (2018) used an employment data approach for ownership forms[3], to show that private firm employment grew from 1% in 1992 to 20% in 2010. Since employment data includes small firms, this sharp increase in private firm activity from 1992 was due to the privatization of TVEs as they faced up to low productivity because of inefficient incentive mechanisms. The provincial level decline in SOEs was between 53-18% during this same period (Andersson et al., 2018). With this changing composition of ownership forms, innovation became more prevalent among manufacturers because private firms had a bigger incentive to do so. Since SOEs were financially backed by the state-owned banks and because managers could not reap the benefits of improved productivity, the motivation for efficiency and cost-reductions was low. Therefore, SOEs did not innovate as much as private firms. Furthermore, SOEs maintained strong ties with local governments which allowed them to be passive in complying to environmental regulations. This protectionism which supported the pro-growth strategies of local governments, meant that SOEs were lazy in turning to innovation for greater productivity (Jiang et al., 2014)

[3] Employment data includes private enterprises with 8 or more employees

Since it is generally financially larger firms that have the capacity to innovate, this study will pay particular focus to the emergence of larger private firms. Hence, figure 1 shows the rapid growth in private industrial enterprises with a designated size of 100 million RMB over the first 10 years of the 21st century and also highlights the substantial growth between 2003 and 2004 when private property rights were formally recognized. Where the increase in private firms from 1992 onwards was due to the privatization of TVEs, the increase in larger private enterprises from the late 1990s was more from the privatization of SOEs as they too faced up to low levels of productivity (Baek, 2005). These private enterprises that gradually took over the market during this nearly 20 year period from 1992 were more profit-oriented and had a bigger appetite for growth and cost reductions, recognizing greater efficiency as an important goal to strive towards thanks to the managers being the residual claimants to the company's profits (Nee & Opper, 2012).



Source: NBS (2019)

Throughout this same period, labour costs also started rising which is one of the reasons why manufacturing firms began to move up the export sophistication ladder and produce more high-tech products as the marginal gains from producing low value goods had been exhausted (Rodrik, 2006). Another reason being the growing existence of cheaper competitors in other east Asian nations such as Vietnam and Thailand (Weiss, 2005). It was around this period that manufacturing firms began looking at innovation as the key to efficiency gains and continued growth. Furthermore, during this time private enterprises were notoriously discriminated against by state-owned banks. Due to this difficulty in accessing the necessary finance needed to grow, firms needed to seek out greater productivity as a means of continued growth (Nee & Opper, 2012; Andersson et al., 2018).

Although most industries within the manufacturing sector as a whole saw major increases in the number of firms operating from 1992 and into the 2000s[4], the industry with the largest growth was in machineries which expanded by over 12 times (Wei & Tang, 2017). Its worth adding that foreign-owned industrial enterprises increased their presence from 5% to 13% during this same period[5] (Wei & Tang, 2017). Foreign owned firms are known to bring in established and more advanced technologies to a developing economy. Through avenues such as "learning by doing", licencing contracts, and importation of foreign skilled labourers, spillover effects can induce local domestic manufacturing firms to adopt new technologies, an important feature to remember when discussing the manufacturing sectors relationship with innovation and emissions (Yueh, 2006).

3.2 | CO2 Emissions in China

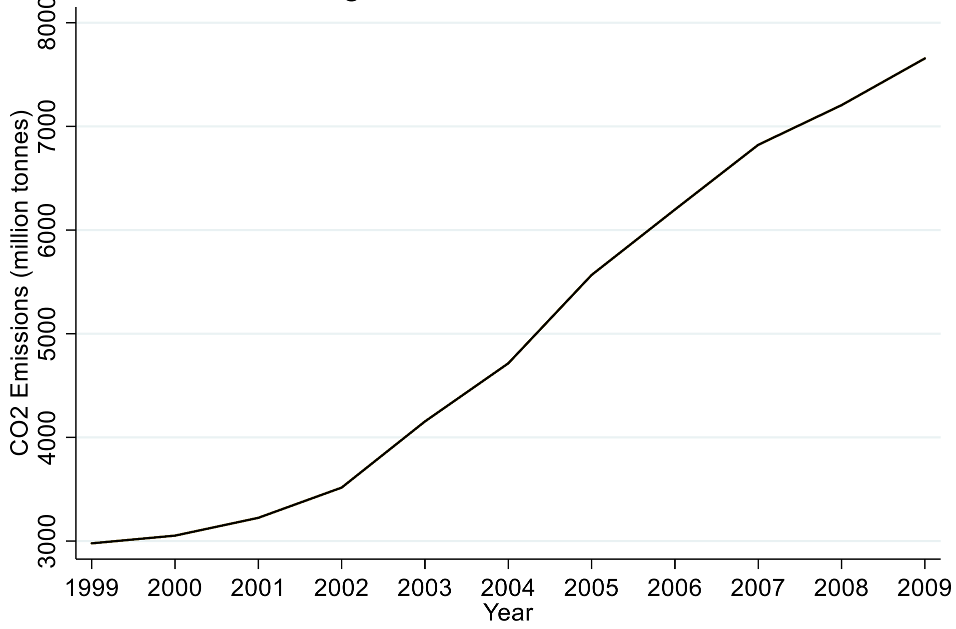
Since 1978, due to China's initial heavy industry-oriented development strategy and then from its exporting boom in manufacturing, there has been a growing burden on the environment with respect to the continued use of non-renewable sources of energy as well as increased levels of pollution and greenhouse gas emissions (GHG). One particular GHG emission is from Carbon dioxide (CO_2) which comes from the combustion of fossil fuels as a source of energy. This form of energy consumption has led to climate change and adverse effects on the environment and human society (Zhou et al., 2018). Since 2007, China has been the largest CO_2 emitter in the world. In fact, although China has already seen extreme levels of development in the last three decades, as things stand given the current pace of industrialization, urbanization, and the ever-increasing demand for transport, energy consumption from fossil fuels is expected to increase continuously for several more decades (Zhou et al., 2018; Andersson & Karpestam, 2013). Provincial level CO_2 emissions data calculated by Shan et al. (2018) is used in this study. Figure 2 shows the growth in emissions across China between 1999 and 2009. A large portion of this growth has been in the coastal region which has seen the most urbanization and industrialization throughout China's

[4] Exact period is 1998-2007

[5] For a more detailed analysis of the changing composition of the Chinese Manufacturing Industry, see Wei and Tang (2017)

economic transformation. However, it has been shown that the effect of industrialization on emissions is strongest in the Intermediate region due to a larger building industry,

Figure 2: CO2 Emissions



The manufacturing industry in China has been at the heart of this rapid industrialization and has accounted for 58% of total CO2 emissions between 1995 and 2015 (Liu et al., 2019). In fact, CO_2 emissions from China's manufacturing industry increased by 220% during this same period, hence why curbing emissions growth has been placed at the forefront of the CPCs agenda in recent years (Liu et al., 2019). Following China's entry to the WTO in 2001, trade volumes increased substantially, which explains the growth in the manufacturing industry during this same era. China's huge trade surplus, thanks in part to a pegged undervalued currency, and its positioning as the supplier of emissions intense products to foreign consumers has resulted in significantly negative effects for the environment. Therefore, trade liberalisation has ultimately become a factor in explaining China's high energy consumption (Andersson, 2018). Domestic consumption has also played a role. China's GDP per capita increased by approximately 260% between 1999 and 2009 meaning more people have been able to consume above the basic necessities, ultimately resulting in higher energy consumption (NBS, 2019; Xu et al., 2012). Many studies have found CO_2 emissions and GDP per capita to be cointegrated meaning there is a long run relationship between emissions and GDP per capita in China (Xu et al., 2012; Wang et al., 2011).

Another avenue through which CO_2 emissions were allowed to increase in China to the extent that they did was with the formation of fiscal federalism, granting local jurisdictions the residual income over surplus revenue generated in their area (Han & Kung, 2015). Specifically, reformed tax laws in 1994 assigned local governments exclusive rights to enterprise and business taxes (Han & Kung, 2015). This pro-growth strategy resulted in local governments offering incentives and supporting local manufacturers which often included tolerating heavy pollution and not following environmental regulations, as they relied on these firms for tax revenue and jobs (Andersson, 2018; Bai et al., 2004). As Jiang et al. (2014) explains, local protectionism was at play as many manufacturers and energy intensive industries had strong connections with the local government. This can be rooted in the fact that Chinese environmental institutions remained weak during this period, allowing industries to keep costs low and have a competitive advantage (Andersson, 2018). Compliance of environmental regulations before 2006 had remained generally ignored; however, the 11th Five Year Plan (2006-2010) set out for stronger enforcement of environmental regulations with the central government determined to promote better standards of energy consumption (Grano, 2016). The CPCs 12th Five Year Plan (2011-2015) aimed to reduce energy intensity by 16% and CO_2 emission intensity by 17%. (NPC, 2011). More recently, they have set out goals for emissions to start declining in the coming decades however current policies and the inadequate promotion of low-carbon development implies that these goals may not be reached (Zhou et al., 2018). Despite this, CO_2 emissions intensity (CO2 emissions per unit of GDP) and energy intensity have been declining in the last two decades (Chen et al., 2019; Wang et al., 2012) (See figure 3). It has been shown that energy price increases, more research & development, changes in ownership structures towards more profit-oriented operations, and a gradual shift in industry towards the services sector have been the main factors explaining the declining energy and CO_2 emissions intensity (Fisher-Vanden et al., 2004

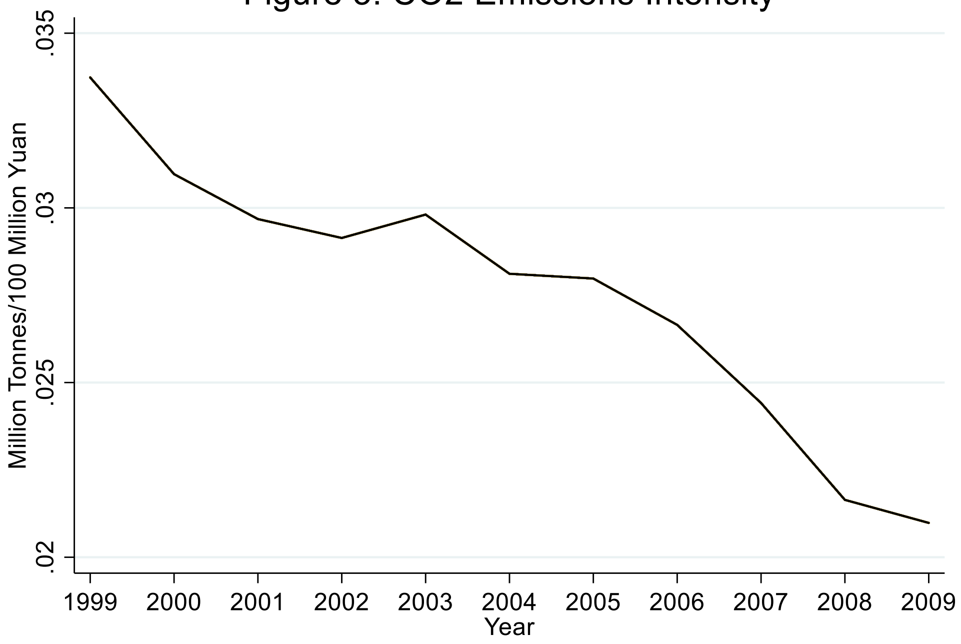


Figure 3: CO_2 Emissions Intensity

3.3 | Patents & Innovation in China

Throughout the 1980s and 1990s, the Chinese manufacturing sector enjoyed a very low capital-output ratio[6] as they allowed foreign technologies to flood in following the country's opening up (Dollar, 2013). Labour costs were low and the pro-export strategy during this period, which involved pegging the currency to give a competitive advantage to domestic manufacturers, allowed firms to maintain large returns without paying much attention to efficiency (Bai, Hsieh, & Song, 2016). However, second generation technology improvements didn't have the same impact on growth. Dollar (2013) has showed that the capital-output ratio started to rise in the 2000s as labour costs rose, efficiency gains exhausted and marginal productivity of capital began to dwindle, indicating a misallocation of resources. As the composition of firm ownership types within the manufacturing sector changed in this period, private enterprises began looking at investment in R&D as a means of maximizing productivity (Andersson et al., 2018). For most developing economies, technology transfers from more advanced foreign economies are seen as the primary source of innovation since consumers in developed economies are more demanding and there are better R&D resources for firms (Sun, 2002). One of the CPC's primary reasons for opening up and allowing FDI was as a "catch-up" strategy to absorb foreign technologies as a way of modernizing the economy (Yueh, 2006). However, moving into the early 2000s it has been

[6] The capital-output ratio shows how much capital is needed to produce one unit of output. See Dollar (2013).

shown that in-house R&D efforts became the primary source for technological improvements and efficiency gains within industrial enterprises (Sun, 2002). Given this drive to improve efficiency within the production process, there can exist a positive effect on emissions; namely, firms would have invested in R&D with the goal of reducing costs and utilizing resources more effectively which can lead to overall lower levels of energy consumption (Fisher-Vanden et al., 2004; Fan et al., 2016; Andersson et al., 2018). However, some manufacturing firms could have also taken the opposite stance, in that they were forced to cut costs to stay competitive, leading to the adaptation of cheaper but more energy intense dirty technologies and environmentally damaging practises (Jiang et al., 2014). That said, environmental technology patents[7] increased substantially between 1999 and 2009, along with patents for chemicals, electronics, and other manufacturing which are all primarily aimed at productivity and efficiency increases (See figures 4 and 5). These forms of innovation can either directly or indirectly lead to better energy efficiency, which has been shown to play the most evident role in carbon emissions abatement in China (Zhang et al., 2017). Given the fact that special economic zones (SEZs) and hi-tech industrial development zones were established along the coastal provinces in the 1990s, it is no surprise to see that this region accounted for the majority of patent applications in all categories between 1999 and 2009 (see figure 6 and appendix 3-5). For instance, Cheung and Lin (2004) found that provinces with more FDI have more patent applications due to spillover effects such as licencing contracts and "learning by doing".

[7] The number of environmental technology patents is significantly lower than the three other patent categories. This is because the environmental technology category only contains one patent classification, whereas the other three categories contain a number of patent classifications. See appendix for a breakdown of the 4 patent categories.

Figure 4: Environmental Technology Patents, 1999-2009

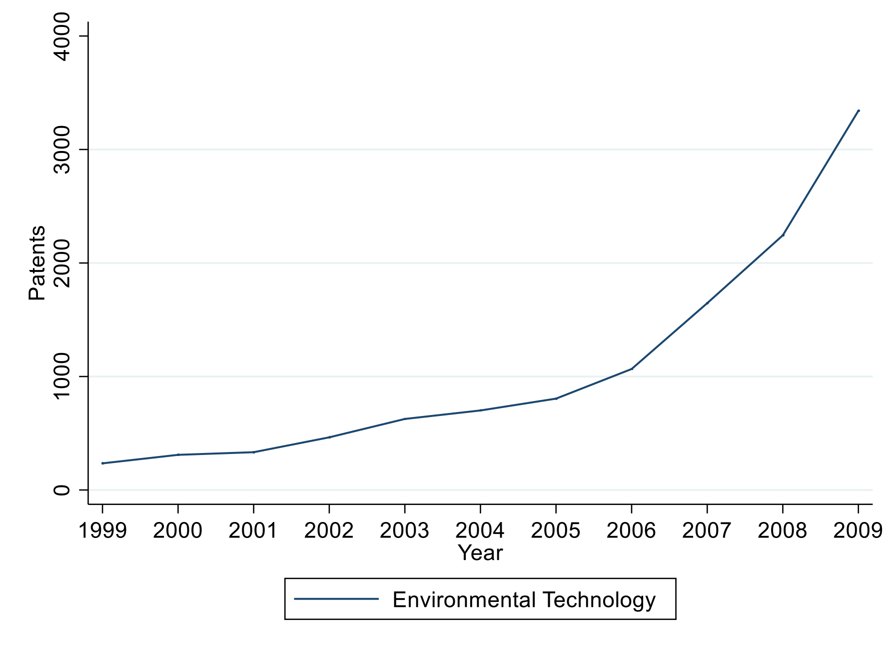


Figure 5: Chemicals, Electronics, & Other Manufacturing Patents, 1999-2009*

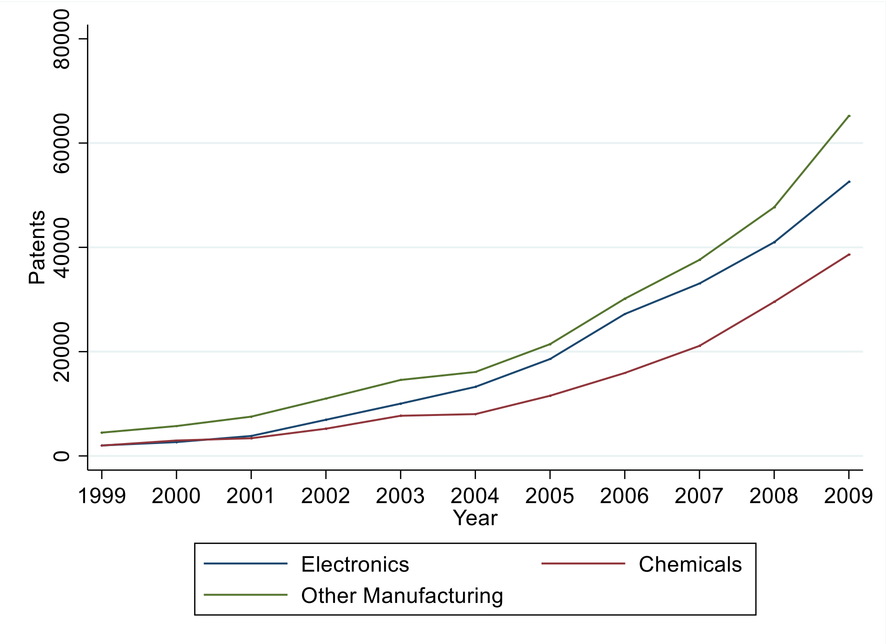
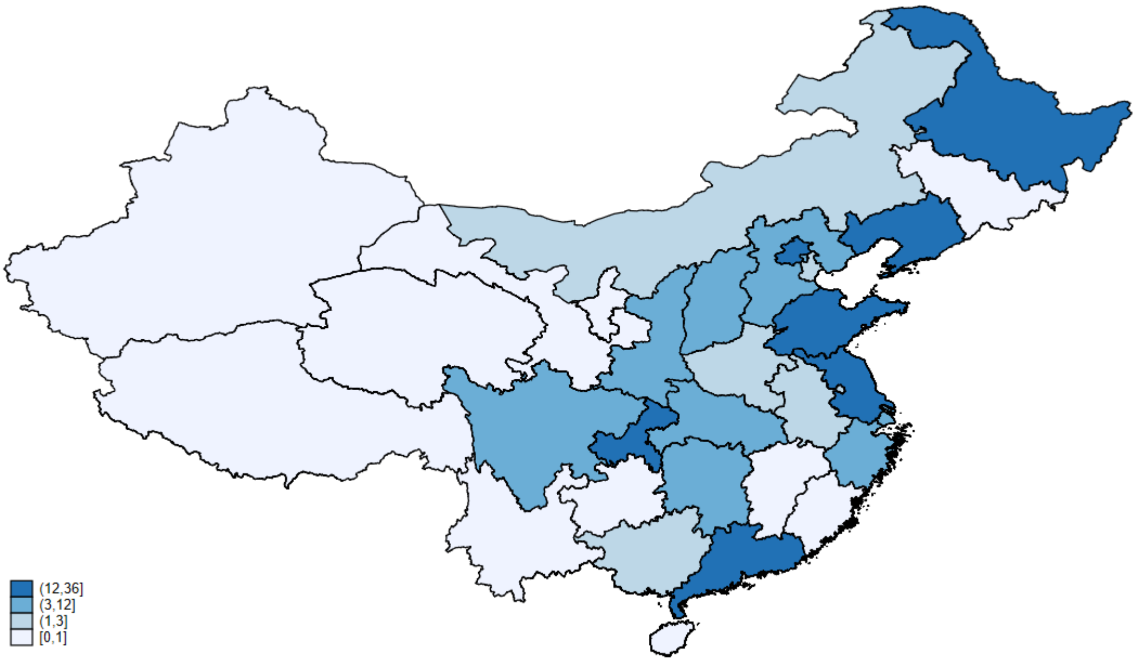
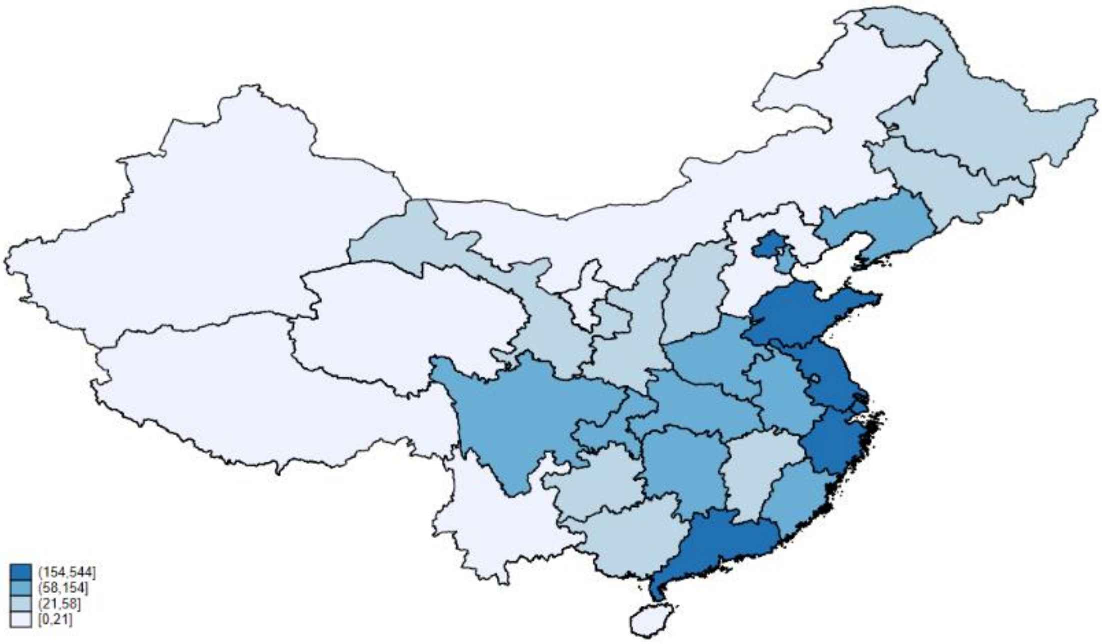


Figure 6: Environmental Technology Patents

1999



2009



Upon joining the WTO in 2001, China was obliged to adopt the trade-related intellectual property rights (TRIPs) agreement, which among other things set out to harmonize their intellectual property rights (IPR) with international standards (Yueh, 2006). It has been shown that better formal institutions can promote firm innovation in China. The NERI index of marketization directly reflects the development of these formal institutions which has been gradually rising in China, especially after it joined the WTO in 2001 (Qu, 2014). Legal institutions are a component of this index and are an important factor determining firm innovation since it offers protection for innovators which can reduce the risk and costs associated with innovation (Qu, 2014). Therefore, the growth in the strength of legal institutions should tend in the direction of greater firm innovation. However, it has been shown that stronger legal institutions actually have no impact on the promotion of firm innovation in China (Qu, 2014). Patent fillings soared throughout the period under study and in 2010 China became the top country in the world for domestic patent applications (Christodoulou et al., 2018). One possible explanation as to why private firms still continued to innovate in the presence of poorly enforced intellectual property rights is because private firms were formed through bottom up processes of informal networks and institutions which created close knit ties of firm owners who shared resources, customer and supplier networks, and who were happy to collaborate and share ideas (Nee & Opper, 2012). In this view, risk of expropriation or intellectual theft may have been less important for private firms. Furthermore, Fang, Lerner, and Chaopeng (2017) have showed that innovation significantly increased after a state-owned firm was privatised and Snyder (2012) found that increased filings of patents and trademarks, greater brand awareness, and more successfully defended IPR dispute court cases have tended to the notion that China's views on IPR are improving although are still imperfect. Thus, even in the absence of strong property rights institutions, this first wave of private industrial enterprises in the early 2000s still invested in R&D and sought technological innovation as a means of greater productivity (Yueh, 2006).

The CPC's 12th Five Year Plan (2011-2015) called for an innovation-driven development strategy as a means of shying away from an unsustainable investment heavy approach (Zhang et al., 2017). Running in parallel to this new strategy was China's CO_2 emissions abatements targets with the promise of lowering emissions intensity by 60% by 2030 (Zhang et al., 2017). Hence, innovations aimed at reducing energy consumption will be at the top of China's development model moving into the future. It has already been shown that some energy technology innovations can help alleviate the emissions crisis in China. For instance, Wang et al. (2012a) used energy technology patent data in China between 1985 and 2009 to show that the increase in these patents did not reduce CO_2 emissions in the long or short-run but did help to reduce emissions intensity in the long-run. Similarly, Wang et al. (2012b) split energy technology patents into fossil-fuelled and carbon-free technologies recognizing the potentially different roles that these innovations play on carbon emissions abatement; finding that there exists a long-run causality among both carbon-free and fossil-fuelled technology patents, CO_2 emissions, and GDP. Crucially, in this study, Wang et al. (2012b) found that patents for fossil-fuelled technologies had no effect on emissions reductions but patents for carbon-free technologies were found to help reduce emissions in China. Thus, energy technology innovations aimed directly at emissions abatement will prove to be strategically important for industrial enterprises as they seize early mover advantages within new green technology markets and as they face up to rising relative energy prices (World Bank, 2013; Fisher-Vanden et al., 2004). Other technological innovations aimed primarily at greater productivity of capital and labour may also indirectly lead to a shift towards low-carbon energies (Mensah et al., 2018; Andersson et al., 2018).

In summary, the pro-growth strategy of the CPC since the reforms began in 1978 has allowed the manufacturing industry to enjoy continued rapid growth. The composition of firms in this sector also changed dramatically over this period, to comprise of mostly profit-maximising private enterprises. The benefits of this economic growth came at the cost of growing environmental degradation in the form of heightened levels of pollution and GHG emissions, and to combat this, the push for an innovative and sustainably led growth strategy has been prioritized by the government in recent years. Therefore, this period represented a point in which these trends, namely the growing emersion of private enterprises, the high levels of CO2 emissions, and the beginning of the age of innovation; somewhat intersected. Accordingly, learning the lessons from this first wave of profit-maximizing firms as they engaged in innovative activities in the search for greater efficiencies may give insight into the specific forms of innovation that induce the greatest effect on CO_2 emissions. Examining the relationship that certain patents within the manufacturing sector have on emissions may lead to these insights.

4 | Empirical Analysis

4.1 | Data

Although the true emergence of the profit-oriented private market in China began in 1992 following the conception of the socialist market economy, due to data constraints, the story in this analysis begins in 1999. Further justification for this is as follows: it was around this period that the rise of larger private firms truly took off following the mass privatization of SOEs. This study holds the view that small private firms throughout the 1990s did not engage in much innovation due to financial and resource constraints. Moreover, this period saw the further emergence of private firm activity in the early 2000s thanks to the enactment of property rights reforms. Therefore, analysing the relationship between innovation and emissions from the late 1990s onwards is logical.

Patent data used in this study has been retrieved from the China Patent Data Project (CPDP) which used a matching algorithm to link all patents in the State Intellectual Property Office's (SIPO[8]) database to a list of industrial enterprises from the Annual Survey of Industrial Enterprises (ASIE) for the years 1998-2009 (He et al., 2018). The ASIE is a nationwide mandatory survey conducted by the National Bureau of Statistics which is sent out to a wide range of industries, although mostly consists of manufacturing firms. The ASIE database consists of all ownership types including state-owned enterprises, however the data has shown a clear trend of privatisation with the collection of state-owned firms decreasing from 70% in 1998 to less than 16% in 2005[9] (He et al., 2018). The database consists of 849,647 uniquely identified matched observations at the provincial level comprising of the three different types of patents in China: invention, utility model, and design patents. Invention patents in China are granted for new technical solutions or improvements to a product or process, and utility model patents are granted for new technical solutions or improvements but with a lower degree of inventiveness (IP Insider, 2019). Design patents, however, are granted for the innovation of external features of a product such as the colour, shape, or pattern. Since these innovations provide little in the way of changes in the production process of manufacturing firms which is the central aim of this analysis, these patents were excluded, leaving a total 757,167 observations.

Each patent in this database is classified through an International Patent Classification (IPC) code. This IPC code has a tree-like structure allowing the particular innovation to be linked to a specific technological field. For example, a code beginning with "F" classifies the patent into the broad category of "Mechanical Engineering; Lighting; Heating; Weapons; Blasting". If the code contained "F23", it would fall under the more specific sub-category of "Combustion Apparatus; Combustion Processes", and then "F23G" would classify the patent under "Cremation Furnaces; Consuming Waste or Low-Grade Fuels by Combustion". Finally, "F23G 1/100" would be the sub-category with the highest level of detail, signifying

[8] Since August 2018, SIPO is now formally recognized as the China National Intellectual Property Administration (CNIPA)

[9] For a more detailed description on the composition of firms in the ASIE database and to read more on the details of linking SIPO patent data to the ASIE database, see He et al. (2018).

the patent under “Methods or Apparatus Specially Adapted for Cremation of Human or Animal Carcasses”. Using this method, the patents in the database were grouped into 35 technological classifications in accordance with WIPO (2008), and then further grouped into 4 manufacturing patent classes for the purpose of this study.

Provincial level GDP and population data were retrieved from the NBS and China Statistical Yearbooks between 1999-2009. In order to have a more balanced panel dataset with complete information, Hong Kong, Macao, Taiwan, and Tibet were excluded. Finally, provincial level CO_2 emissions data was retrieved from Shan et al. (2018)

4.2 | Variables

Dependent Variable

CO_2 emissions was chosen as the main indicator of environmental degradation because China is, by a considerable margin, the largest emitter of carbon dioxide in the world. Considering urbanization and industrialization are set to continue in China for years to come, the combustion of fossil fuels as a source of energy will be in greater demand. Hence, the issue of carbon emissions abatement via a shift to more environmentally friendly sources of energy and better energy-efficient processes within industrial enterprises will prove to be vital in the coming years if China wants to reach its emissions reduction targets.

The Chinese government has only published provincial level CO_2 emissions data for a small number of years using an unfamiliar method. Given this, a number of independent scholars and institutes have manually calculated provincial level yearly carbon emissions by multiplying consumption of energy sources by emissions factors. Most attempts to calculate China’s emissions are done using emissions factors recommended by IPCC. However, Shan et al. (2018) has shown that these default emissions factors are around 40% higher than a survey they conducted on China’s fossil-fuel quality and cement process due to the fact that the usage of energy improves over time. Hence, Shan et al., (2018) used updated emissions factors to calculate China’s provincial carbon emissions which will be used in this study. A noteworthy point is that these estimates were found to be the lowest of all the independent estimates of China’s CO_2 emissions, due to these emissions factors being lower than the IPCC default values (Shan et al., 2018). Based on the decomposition literature, CO_2 emissions intensity (CIE) will also be used to measure the effect of innovation on the environment. This refers to CO_2 emissions intensity per unit of GRP. CIE is slightly different than pure emissions levels as it reflects the energy and economic performance of a country, and since it is included in many of Chinas emissions abatement goals, it can be a useful indicator in helping to identify what is most effective in driving down emissions in China (Dong et al., 2018). Emissions data was transformed into logarithmic form to eliminate the possibility of heteroskedasticity (Verbeek, 2014).

Explanatory Variables

The main explanatory variables are patents. The 35 technological classifications have been grouped into 4 different patent types in order to shed light on what sort of innovations have induced a change in carbon emissions. The four patent types are as follows: Environmental Technology, Chemicals, Electronics, and Other Manufacturing. See appendix 1 for a detailed breakdown of these four patent types. Patent data was also transformed into logarithmic form.

Control Variables

This study adopts an IPAT framework to model the impacts of humans on the environment. IPAT is an acronym for three factors that affect the environment: population (P), affluence (A), and technology (T). Therefore, controlling for these factors that affect emissions is necessary in order to isolate the effect that technological innovation has on the environment. Studies have shown that as an economy develops there is more economic activity which leads to an increase in demand for energy and subsequently higher carbon emissions (Mensah et al., 2018). It has also been shown that there exists a unidirectional relationship running from GDP to emissions among both developed and developing economies, including China (Mbarek et al., 2015; Huang & Lu, 2011). Hence, controlling for GRP per capita or “affluence” in an IPAT framework, is essential in modelling the effect that innovation has on emissions. Population has been shown to play a significant role in determining carbon emissions, since a higher population implies greater demand for energy consumption (Dietz & Rosa, 1997). In China, urbanization has resulted in large changes in the amount that people use transport and consume energy. Further, it has been shown that these activities vary according to household size, so controlling for population is essential within an IPAT framework (O’Neill & Chen, 2002). In line with the EKC curve, adding a quadratic function of GRP per capita may capture a possible non-linear relationship between economic growth and the environment (Mensah et al., 2018). The final control variable included in this analysis is the NERI index. This is a score between 0 and 10 comprising of 5 main indicators that describes the capacity of each province to adopt to a contemporary market structure (Gang et al., 2012). The 5 indicators are: “Government-market relations”, “Development of the Nonstate enterprise sector", "Development of the commodity market", and "Development of factor markets and Intermediate/legal framework". Since the index is essentially a measure of how conducive a province is to doing business, it can also be used as a measure of how conducive the area is to innovation; especially since part of the index comprises a measure of property rights protection, legal environment, and patent activity. Including the NERI index as a control variable may help to better isolate the effect that technological innovations have on emissions.

4.4 | Summary Statistics

Table 2 displays summary statistics of the key variables used in this study. The sample includes 30 provinces across 11 years (1999-2009) amounting to 330 observations.

Table 2: Summary Statistics*

	1999				2004				2009			
	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max
Dependent Variable												
CO2 Emissions Intensity	0.04	0.02	0.02	0.09	0.04	0.02	0.01	0.12	0.03	0.01	0.01	0.06
CO2 Emissions (million tonnes)	99.27	59.02	8.10	222.80	157.16	101.17	17.20	397.70	255.20	167.79	27.00	717.90
Explanatory Variables												
Environmental Technology Patents	7.83	9.55	0	36	23.37	29.35	0	110	111.37	129.33	0	544
Electronics Patents	66.27	129.51	0	687	440.17	1059.15	0	5529	1746.73	3645.80	7	18934
Chemicals Patents	65.97	64.16	0	252	266.97	301.38	6	1254	1287.03	1397.39	44	5505
Other Manufacturing Patents	148.80	224.19	4	926	535.80	800.91	4	3252	2171.17	3113.14	11	11066
Control Variables												
GRP per capita	7852.07	5379.39	2545	27071	14223.37	9869.48	4317	46338	28649.07	15628.87	10971	69165
Population (10,000 Persons)	4136.13	2553.17	507	9391.7	4291.53	2649.39	539	9717	4404.90	2692.59	557	10130
NERI Index (Total Marketization)	4.12	1.03	1.720	5.960	6.25	1.78	3.100	9.810	7.57	2.05	3.250	11.800

*Mean values across all provinces (excluding Hong Kong, Taiwan, Macau, & Tibet)
Source: National Bureau of Statistics of China (NBS), 2019 & Chinese Patent Data Project (CPDP), Nature Scientific Data

Based on these descriptive statistics, several insights can be extracted. Firstly, it is interesting to note that although carbon emissions increased quite rapidly over this period, carbon emissions intensity has actually declined. The province with the highest emissions intensity in 1999 was Shanxi, due to it having large coal deposits and is the state with the highest number of coal companies. The highest provincial emissions continued to rise until peaking in 2003 (Ningxia) and has continued to decline ever since. The variance of emissions intensity has also declined over this period, as a result of southern and coastal regions catching up with the heavy-industry dominated northern provinces due to continued urbanization and industrialization. All four patent categories experienced rapid growth throughout this period. For instance, electronics patents increased from a mean of 66.27 in 1999 to 1746.73 in 2009, which gives a clear indication that companies during this period began looking at innovation as a way of continued growth in the presence of rising labour costs. Guangdong province witnessed the highest number of electronics patents in 2009 as a result of Shenzhen city establishing itself as the electronics manufacturing hub of China. As depicted in the environmental technology patent heatmap in figure 6, it is no surprise to see that the majority of patent applications were filed in the coastal provinces, which has been home to innovative foreign firms, SEZs, hi-tech industrial development parks, and skilled laborers since the 1990s. This finding can also be seen in table 2, as the majority of the total growth in patents was observed among the few high-patent activity provinces in the coastal areas, whereas the western provinces did not witness any substantial increase over this period from their very low number of patent applications in 1999. In other words, patent applications seemed to have increased in concentration among the coastal provinces throughout this period. Hence, there are certainly regional differences with respect to patent activity which may be early evidence in the way of proving H3.

As a result of continued economic growth, it is no surprise to see that GRP per capita has increased significantly over this period; increasing by over 264% between 1999 and 2009. The pace of urbanization in China can also be shown in the population statistics; the gradually increasing standard deviation showing that there is greater variation among the provinces as rural to urban migration persisted throughout these years. Finally, in terms of marketization, the NERI index statistics show that the average province in China has improved in terms of being a conducive environment to business and innovation; the mean value increasing from 4.12 in 1999 to 7.57 in 2009.

4.5 | Model Specification

This study applies the use of panel data to conduct the analysis on innovation and emissions. Panel data contains a cross-sectional and a time dimension, which leads to greater efficiency of estimators and can allow for identification of unbiased estimators in the presence of omitted variables (Verbeek, 2014). A fixed effects panel data model was chosen because there are a fixed number of provinces. Further justification to using fixed effects is because a random effects model holds an assumption that the unobserved, time-invariant, error term has zero correlation with the independent variables (Verbeek, 2014). Since, this study holds strong belief that some of the unobserved province specific factors in China that do not vary over time, such as geographic location and factor endowments, are not exogenous to the independent variables, a more appropriate model to use is a fixed effects model. Furthermore, this study also assumes heterogeneity between provinces and over time, so using a fixed effects estimator may be more applicable. The error term in a panel data model can be divided into two parts, one term that varies over time and one term that does not vary over time. The term that does not vary over time can become fixed for each panel, and thus by including it in the model, one can implicitly control for observed and unobserved province-specific factors that are constant over time; thereby removing a source of omitted variable bias (Angrist & Pischke, 2009). Similarly, a fixed time effect can be included in the model to capture the effect of all observed and unobserved variables that don't vary over provinces (Verbeek, 2014). To avoid spurious results arising from regressing on non-stationary variables, a Lewin-Lin-Chu (LLC) unit root test was performed on most variables. Due to there being several missing variables in the emissions data, a Fisher-Type Augmented Dickey-Fuller unit root test was instead conducted on CO_2 emissions and CIE to determine non-stationarity. The results of these tests are displayed in appendix 2. First differences were calculated for all variables that were non-stationary, which will therefore establish growth rates instead of levels.

In order to determine what lag length between patents and emissions resulted in the best fit for the data, several regressions were ran using 1 and 2 year lags on the patent variables to identify which specification resulted in the lowest Akaike Information Criterion (AIC). The tests revealed that lagging environmental technology & electronics patents by 2 years and lagging chemicals & other manufacturing patents by 1 year resulted in the lowest AIC for both models. This combination of lag lengths was hence chosen for the benchmark regressions. Further regressions were also ran with a 1-year lag on all patents to analyse the more immediate effects that innovation has on emissions since the AIC for this specification was not substantially larger.

The presence of heteroskedastic error terms in a model can result in less efficient estimators (Verbeek, 2014). Therefore, a "modified Wald statistic for groupwise heteroskedasticity in the residuals of a fixed effect regression model" was conducted, with the null hypothesis being that the error terms have constant variance. The test proved highly significant, so robust standard errors were instead used in the model. Furthermore, all variables were transformed into logarithmic form to help reduce the presence of heteroskedasticity.

After transforming the necessary variables into log form and first differences, as well as lagging the explanatory variables, the following model will be used to test the relationship between technological innovation and CO_2 emissions:

Eq. 1:

$$\Delta\ln(CO_2)_{it} = \alpha + \beta_1\Delta\ln(ET)_{it-2} + \beta_2\Delta\ln(ELECT)_{it-2} + \beta 3\Delta\ln(CHEM)_{it-1} + \beta 4\Delta\ln(OM)_{it-1} + \beta_5\Delta\ln(X')_{it} + \delta_i + \gamma_t + \varepsilon_{it}$$

In eq. 1, the dependent variable is the growth of log CO_2 emissions, for province *i* in year *t*. The change in the log transformed explanatory variables are also included with their respective lags. $\Delta ln\ X'$ is a vector of controls that include GRP per capita, GRP per capita squared, population, and the NERI index. A fixed effect term (δ_i) is included in the model to account for unobserved differences between provinces that don't vary over time. For example, the northern provinces have been endowed with large coal reserves, and so the composition of industry in those provinces will be more energy intensive than southern provinces. Similarly, the time effect (λ_t) will capture any factors that have affected all provinces equally, such as new environmental regulations or property rights reforms during this period that gave official recognition to private enterprises. Finally, an error term (ε_{it}) is included to capture the remaining unobserved factors that effect carbon emissions.

Eq. 2:

$$\Delta\ln(CIE)_{it} = \alpha + \beta_1\Delta\ln(ET)_{it-2} + \beta_2\Delta\ln(ELECT)_{it-2} + \beta 3\Delta\ln(CHEM)_{it-1} + \beta 4\Delta\ln(OM)_{it-1} + \beta_5\Delta\ln(X')_{it} + \delta_i + \gamma_t + \varepsilon_{it}$$

CIE can be utilized to measure carbon emissions performance, and since many of China's emissions abatement targets specifically involve reduced CIE, including it as a dependent variable in this analysis is important. Therefore, eq. 2 will be used to examine how technological innovations have affected carbon emissions intensity, ceteris paribus. Similarly, the main explanatory variables and vector of control variables are included in this model. Lastly, a province fixed effect and time effect is also included in eq. 2 as well as an error term for any unobserved variation.

Since this study is proposing that some manufacturing firms will innovate for the purpose of energy and cost reductions in the production process, equations 3 and 4 will be used to examine the more immediate effects that innovation may have on emissions by lagging all patents by 1 year. *X'* is the vector of control variables, and the aforementioned fixed and time effects are also included in these models.

Eq. 3:

$$\Delta \ln(CO_2)_{it} = \alpha + \beta_1 \Delta\ln(ET)_{it-1} + \beta_2 \Delta\ln(ELECT)_{it-1} + \beta 3 \Delta\ln(CHEM)_{it-1} + \beta 4 \Delta\ln(OM)_{it-1} + \beta_5 \Delta\ln(X')_{it} + \delta_i + \gamma_t + \varepsilon_{it}$$

Eq. 4:

$$\Delta \ln(CIE)_{it} = \alpha + \beta_1 \Delta\ln(ET)_{it-1} + \beta_2 \Delta\ln(ELECT)_{it-1} + \beta 3 \Delta\ln(CHEM)_{it-1} + \beta 4 \Delta\ln(OM)_{it-1} + \beta_5 \Delta\ln(X')_{it} + \delta_i + \gamma_t + \varepsilon_{it}$$

All four equations represent changes in the growth of technological innovation and its corresponding effect on the growth of emissions and carbon emissions intensity (CIE). Therefore, given the logarithmic transformations of the key variables, the interpretation of the findings in the following results section will be in the language of percentage changes in the growth rate

6 | Results

6.1 | Benchmark Results

Table 3 displays the results from the regressions using the transformed models. The specifications that use carbon emissions as the dependent variable are shown in column 1 & 2 and column 3 & 4 use carbon emissions intensity as the dependent variable. Column 2 & 4 display the results using GRP per capita squared as a control instead of GRP per capita to capture possible non-linearity in line with the EKC theory. The model's goodness of fit is slightly better for the emissions intensity specifications with an R^2 of 0.323 compared to the emissions regressions with an R^2 of about 0.245. Panel-data model Wald tests for autocorrelation were conducted across all regressions (Woodridge, 2002). These tests did not prove significant indicating no presence of autocorrelation. With environmental technology & electronics patents lagged by 2 years and chemicals & other manufacturing patents lagged by 1 year, the results indicate a strong positive relationship between electronics patents and emissions. Specifically, column 1 shows the results from regressing emissions growth on patents growth with GRP per capita, population, and the NERI index used as controls. The coefficient on electronics patents is significant at 1% and can be interpreted as follows: a 1% increase in the growth of electronics patents can lead to a nearly 3.3% increase in the growth of carbon emissions, ceteris paribus. This relationship is slightly larger when using GRP per capita squared as a control in column 2. A possible explanation for this positive relationship is that more electronics innovations within manufacturing firms such as new telecommunications and computer technologies may have induced a greater demand for energy consumption via the powering of devices, since this period represented widespread adoption of personal electronic devices such as computers and mobile phones; while also representing the beginning of growth in the services sector.

Table 3: Benchmark Results

Dependent Variable =	(1) Δln CO_2 Emissions	(2) Δln CO_2 Emissions	(3) Δln CO_2 Emissions Intensity	(4) Δln CO_2 Emissions Intensity
Env.Tech. Patents *(2-Year Lag)*	0.015	0.015	0.014	0.014
	(0.011)	(0.011)	(0.011)	(0.011)
Electronics Patents *(2-Year Lag)*	0.033***	0.034***	0.038***	0.036***
	(0.011)	(0.012)	(0.012)	(0.012)
Chemicals Patents *(1-Year Lag)*	0.046*	0.050**	0.049*	0.048*
	(0.025)	(0.025)	(0.025)	(0.024)
Other Manufact. Patents *(1-Year Lag)*	-0.017	-0.024	-0.037	-0.030
	(0.033)	(0.033)	(0.033)	(0.034)
GRP per capita	0.000		0.000	
	(0.000)		(0.000)	
Population	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
NERI Index	-0.033	-0.027	-0.030	-0.029
	(0.031)	(0.030)	(0.032)	(0.030)
GRP per capita squared		0.111		-0.208
		(0.152)		(0.153)
Constant	0.443	0.211	-0.003	0.123
	(0.461)	(0.439)	(0.467)	(0.442)
Observations	177	177	177	177
R-squared	0.244	0.246	0.323	0.331
Number of Provinces	28	28	28	28

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

Furthermore, since electronics are lagged by two years, the effect of electronics innovations on emissions might be witnessed through the end users increase in energy consumption rather than from a somewhat immediate change to the production process. However, these results should be interpreted with caution since the number of observations reduced substantially due to the fact that several years of data were lost after differencing and lagging the variables.

Chemicals patents displayed a similar positive relationship with emissions. The results in column 2 show that a 1% increase in the growth of chemicals patents led to a 5% increase in the growth rate of emissions; this being significant at 5%. Chemicals were lagged by 1 year in this specification so the induced change on emissions could therefore be viewed via more immediate changes to the production process. The rapid growth of China's chemicals industry in the absence of any organized development plan with stringent environmental regulations has been a factor explaining the rise of atmospheric pollution, which can subsequently explain the positive relationship that chemicals innovations are shown to have on emissions in table 3 (Deng et al., 2017). These relationships are very similar when regressing with carbon emissions intensity as the dependent variable, seen in columns 3 and 4. Since electronics and chemicals patents are non-green technologies, these findings conform to H2 that some non-green technologies can indirectly induce a change in emissions, although the sign of the coefficients are somewhat unexpected. The theoretical prediction was that innovations in the production process could lead to more energy efficient processes, thereby leading to lower emissions. However, it seems that the positive effect on emissions growth using a 2- year lag could be as result of the continued expansion of the electronics industry during this period.

6.2 | One Year Lagged Patents Results

Given the fact that the central aim of this study is to examine how changes to the production process in the manufacturing sector may induce possible changes in emissions, further regressions were conducted using model 3, which includes a 1-year lag on all four patent categories, with the belief that innovations that result in a change to the production process may have a more immediate effect on emissions via the implementation of more energy-efficient processes. Table 4 displays the results from these regressions for both carbon emissions and carbon emissions intensity. The AIC is slightly smaller for these regressions, and similarly, the R^2 is slightly smaller compared to the benchmark regressions. Nonetheless, a better understanding of the more immediate effects of patents on emissions can still be extracted from the results. In accordance with these predictions, there now exists a negative relationship between electronics and environmental technology patents when only lagged by one year. The results in column 1 show that a 1% increase in the growth of electronics innovations corresponds to a 2.16% decrease in the growth of CO_2 emissions; this result being significant at 5%. Similarly, the growth in environmental technology patents when only lagged by 1 year displays a negative relationship with emissions, however this result is not significant. Nonetheless, the consensus from these findings is that there exists a more immediate negative relationship between some technological innovations and emissions. Similar to the findings in table 3, the coefficient on chemicals is still positive which again can be explained by the fact that the chemicals industry is quite pollutant, so it's possible that chemical innovations during this period would have increased a firm's energy consumption, and consequently its carbon emissions. Accordingly, these results correspond to H2.

Table 4: Results With 1 Year Lagged Patents

	(1)	(2)	(3)	(4)
Dependent Variable =	Δln CO_2 Emissions	Δln CO_2 Emissions	Δln CO_2 Emissions Intensity	Δln CO_2 Emissions Intensity
Env.Tech. Patents *(1-Year Lag)*	-0.010	-0.010	-0.010	-0.009
	(0.010)	(0.010)	(0.010)	(0.010)
Electronics Patents *(1-Year Lag)*	-0.022**	-0.022**	-0.022**	-0.021**
	(0.009)	(0.009)	(0.009)	(0.009)
Chemicals Patents *(1-Year Lag)*	0.038*	0.038*	0.043*	0.037*
	(0.021)	(0.021)	(0.022)	(0.021)
Other Manuf. Patents *(1-Year Lag)*	0.000	0.000	-0.014	-0.002
	(0.025)	(0.025)	(0.026)	(0.025)
GRP per capita	0.000		0.000	
	(0.000)		(0.000)	
Population	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
NERI Index	-0.020	-0.021	-0.017	-0.023
	(0.026)	(0.0251)	(0.027)	(0.030)
GRP per capita squared		0.054		-0.274*
		(0.139)		(0.141)
Constant	0.390	0.387	-0.017	0.331
	(0.389)	(0.368)	(0.398)	(0.373)
Observations	205	205	205	205
R-squared	0.206	0.206	0.260	0.276
Number of Provinces	28	28	28	28

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

However, although the results in table 4 display the expected negative relationship that environmental technology patents have on emissions, it cannot be shown from these findings that they directly result in reduced emissions or emissions intensity, since the findings have weak significance. Therefore, due to this weak significance, H1 must be rejected. There are several explanations for this finding. Firstly, as can be shown in appendix 1, the category of environmental technology patents only includes one technology classification; namely, "Environmental technology", whereas the other three patent categories contain several different technology classifications resulting in a significantly smaller number of patents in the environmental technology category compared to the other three. This may explain why the results are not significant. Secondly, the effect of green technologies on emissions is sensitive to the composition of these technological categories. For instance, Wang et al. (2012b) looked at how energy technology patents affect emissions, by classifying energy technology patents as fossil-fuelled or carbon-free technologies, whereas this study used a different method of classification; namely the "Concept of Technology Classifications" in WIPO (2008) to classify environmental technology patents. Therefore, the different method of classification used to define green technologies in this study may explain the weaker significance in the environmental technology coefficients. Furthermore, it has been shown that there only exists a long run relationship between green technologies and emissions (Wang et al., 2012a). Therefore, the absence of long-term patent data in this study can further explain the weak significance in the environmental technology variable. Finally, due to lagging and transforming the variables into first differences, a number of years were dropped from the analysis, which may result in more short-term variation in the data, which can also explain the weak significance in all the variables. Nevertheless, considering these explanations for weaker significance, the results still indicate that there exists a negative relationship between environmental technology innovations and emissions, a stronger negative relationship with respect to electronics innovations, and finally a positive relationship between chemical innovations and emissions.

A Wald test was conducted to test if there exists a statistically significant interaction between technological innovation and the NERI index. The idea here was that areas with strong legal systems and property rights protection might result in technological innovations having a greater effect on emissions. Since I was unable to reject the hypothesis, the unexpected result was that there was no relationship between areas of high marketization and innovation with respect to emissions. A possible explanation for this result is that industrial enterprises in

China continued to innovate throughout this period despite weak institutions and poor enforcement of intellectual property rights.

6.3 | Regional Results

Previous studies have used patent counts to show that the effect of domestic technological innovation on emissions is different across the three economic regions in China (Wei & Yang, 2010). Wang et al. (2012b) also came to this conclusion using energy technology patents. Therefore, further regional regressions were performed to explore this relationship using the 4 technological innovation categories. Table 5 shows the results from these regressions.

Table 5: Regional Results

	Coastal		Intermediate		Western	
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable =	$\Delta\ln CO_2$ Emissions	$\Delta\ln CO_2$ Emissions Intensity	$\Delta\ln CO_2$ Emissions	$\Delta\ln CO_2$ Emissions Intensity	$\Delta\ln CO_2$ Emissions	$\Delta\ln CO_2$ Emissions Intensity
Env. Tech. Patents*	-0.004	-0.007	-0.015	-0.009	-0.008	-0.009
	(0.011)	(0.011)	(0.024)	(0.024)	(0.022)	(0.022)
Electronics Patents	-0.019	-0.026**	-0.000	0.004	-0.029	-0.028
	(0.013)	(0.013)	(0.022)	(0.021)	(0.018)	(0.018)
Chemicals Patents	-0.000	0.017	0.049	0.027	0.047	0.053
	(0.027)	(0.026)	(0.058)	(0.057)	(0.048)	(0.049)
Other Manuf. Patents	-0.007	-0.024	-0.011	-0.019	0.004	-0.006
	(0.024)	(0.023)	(0.052)	(0.051)	(0.066)	(0.068)
GRP per capita	0.000*	0.000**	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Population	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
NERI Index	-0.006	0.005	-0.041	-0.053	-0.057	-0.071
	(0.018)	(0.017)	(0.073)	(0.071)	(0.105)	(0.108)
Constant	0.240	-0.312	0.112	0.208	0.571	0.560
	(0.258)	(0.247)	(1.276)	(1.254)	(1.488)	(1.527)
Observations	80	80	61	61	64	64
R-squared	0.626	0.640	0.301	0.401	0.191	0.271
Number of Provinces	10	10	8	8	10	10

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

Note: All patents lagged by 1 year

As previously explained, the large majority of patent activity throughout this period was increasingly concentrated in the coastal area. As expected, this region showcases the only significant relationship between technological patents and emissions. Specifically, the results show that a 1% increase in the growth of electronics patents corresponds to a 2.57% decrease in emissions intensity growth. This relationship is similar to the result established in the unrestricted findings in table 4. Generally, the majority of manufacturers in the electronics sector are situated along the coast in clusters such as Shenzhen city in Guangdong province thanks to industrial polices like SEZs and better transport networks. Hence, since electronics manufacturing enterprises are less carbon intensive than other heavy industries, a negative correlation with carbon emissions intensity seems quite reasonable. The absence of a significant relationship between electronics and emissions intensity in the intermediate and western economic regions can be explained by the fact that these inland provinces during this period had not established many hi-tech industries and were still largely agrarian or heavy-industry based. Environmental technology patents display a consistent weak negative effect on emissions across each region. However, the signs on the coefficients of the other technological innovations are not consistent across the three economic regions. For example, in column 1 the effect that the growth in chemicals has on CO_2 emissions growth in the coastal region is positive, compared to the negative relationship across the other two regions. Also, in column 3 the sign on the coefficient for the growth in other manufacturing innovations in the western region is positive compared to the negative signs observed in the other regions. However, it is important to stress that these results are not significant due to growth rates being subjected to larger short-term noise. Moreover, the results for the western and intermediate regions were not expected to display strong significance since the majority of technological innovation and subsequently patent filing activity, was largely carried out and concentrated in the coastal provinces. Considering this, its plausible to allow these findings to correspond to H3 and agree with previous findings by Wei and Tang (2010) that the effect of innovation on emissions is different across the three economic regions.

7 | Conclusion

The rapid transformation of China's economy in the last 30 years has been at the cost of drastically increased levels of pollution and greenhouse gas emissions. After China became the largest emitter of CO_2 emissions in 2007, the CCP placed carbon emission abatement as a priority in its subsequent 5 Year Plan, with the aim of remodelling its growth strategy to allow for sustainable economic growth without increasing environmental degradation. Running in parallel to this movement, manufacturers had to face up the issue of increasing labour costs and an ever-expanding threat of cheaper alternatives in neighbouring countries. Thus, innovation became the key to continued economic growth. On an industrial level; innovations in the production line became the key to solving the problem of rising factor costs, while also allowing domestic Chinese manufacturers to grow in expanding markets through first mover advantages of adopting new technologies. Combining these two movements, this paper set out to explore the possible relationship between innovations in the manufacturing sector and CO_2 emissions levels during this critical era of change between 1999-2009 that also played host to the dramatic rise of profit-oriented private firms.

Previous studies have established that there exists a negative relationship between innovation and emissions in China by focusing solely on the impact that energy and environmental technologies have had on carbon emissions abatement. The aim of this study was to expand on these findings by recognizing that innovative processes can lead to new operations within the production line of industrial enterprises that are more energy efficient and less resource consuming. From this light, innovations do not have to specifically be green technologies to reduce the burden on the environment, since indirect effects from other non-green innovations can result in less carbon emissions. Therefore, this study set out to explore these innovations by expanding the scope to include all technological innovations within the manufacturing sector in China.

The results indicate that there exists a positive relationship between electronics patents and emissions when lagging electronics patents by 2 years and a negative relationship when lagging these patents by 1 year. An explanation for this finding was that the more immediate effect on emissions could be from adopting better energy efficient processes during manufacturing but the positive relationship from a 2-year lag could be from the overall expansion of electronics goods that would eventually increase energy consumption. A second finding was that chemicals patents displayed a consistent positive relationship with emissions over all specifications, which is understandable since the chemicals industry is quite dirty and energy intensive. Finally, environmental technology and other manufacturing patents were shown to have both positive and negative effects on emissions depending on the lag term, although these results were insignificant.

However, it is crucial to point out some drawbacks from this analysis. Firstly, these findings were subjected to larger short-term variation which resulted in lower significance. Ideally, a dynamic panel data analysis applying the use of a VECM would have been conducted to determine short and long run causality between patents and emissions. However, data constraints limited the analysis to a general panel data model in that respect. Furthermore, the use of patent data has two drawbacks. Firstly, it is difficult to establish the length of time between a patent application and the actual adoption of that new technology. Secondly, one cannot be certain that the province where the patent was submitted will also become the province where the innovation will be adopted. For these reasons, it is difficult to establish any causality in findings using provincial level patent data. Hence, any causal interpretation of the empirical results is ill-advised. In saying this, patents are still considered an accurate indicator of innovation that can be used to establish insights into the affect that innovation has on important matters such as the environment going forward.

Nevertheless, the results clearly indicate that some innovations not adopted for any specific emissions abatement goals can indirectly induce a change in emissions. Hence, what this study shows is that including non-green innovations when analysing the relationship between innovation and CO_2 emissions can prove more insightful than focusing solely on energy technology patents. For China specifically, approaching the discussion on innovation and emissions from this view could also give the government a better understanding of the manufacturing sector as they seek to adopt industrial policies and environmental regulations that aim for emissions reductions while also trying not to impede economic growth.

On account of the fact that by the mid-2000s the large marginal returns to capital from the initial adoption of new technologies had been all but vanished, industrial enterprises will have leaned more heavily on technological innovation as the key to sustained growth in more recent years. Considering this, examining the effect that this push for innovation in the last 10 years has had on emissions will be important for Chinese policy makers. Therefore, further possible research suggestions would be to harness updated patent and emissions data from as recent as possible, paying particular attention to include all patent categories, in order to establish what innovations can reduce CO_2 emissions. The use of a long-run time series or dynamic panel data model should be employed to establish causality between all technological patent categories and emissions.

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Appendix

Appendix 1:

Patent Classifications

Environmental Technology	**Chemicals**	**Electronics**	**Other Manufacturing**
Environmental Technology	Analysis of Biological Materials	Electrical Machinery	Handling
	Control	Audio Visual	Machine Tools
	Medical Technology	Telecommunications	Engines, Pumps, Turbines
	Organic Fine Chemistry	Digital Communications	Textiles & Paper Machines
	Biotechnology	Basic Communication Processes	Other Special Machines
	Pharmaceuticals	Computer Technology	Thermal Processes & Apparatus
	Macromolecular Chemistry	IT Methods for Management	Mechanical Elements
	Food chemistry	Semiconductors	Transport
	Basic Materials Chemistry	Optics	Furniture, Games
	Materials, Metallurgy	Measurement	Other Consumer Goods
	Surface Technology, Coating		Civil Engineering
	Micro-Structure & Nano-Technology		
	Chemical Engineering		

Source: WIPO (2008)

Appendix 2:

Unit Root Tests

Lewin-Lin-Chu (LLC)

	Level		First Difference		Second Difference	
Variable	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value
Environmental Technology	4.2308	1.0000	-4.7340	0.0000	-	-
Electronics	4.5095	1.0000	2.2744	0.9885	-8.1162	0.0000
Chemicals	4.1436	1.0000	-5.7100	0.0000	-	-
Other Manufacturing	3.8662	0.9999	-7.1959	0.0000	-	-
GRP per capita	-5.3718	0.0000	-	-	-	-
GRP per capita squared	1.6638	0.9519	-9.0808	0.0000	-	-
Population	-3.0818	0.0000	-	-	-	-
NERI Index	-11.9170	0.0000	-	-	-	-

Fisher-Type Augmented Dickey-Fuller

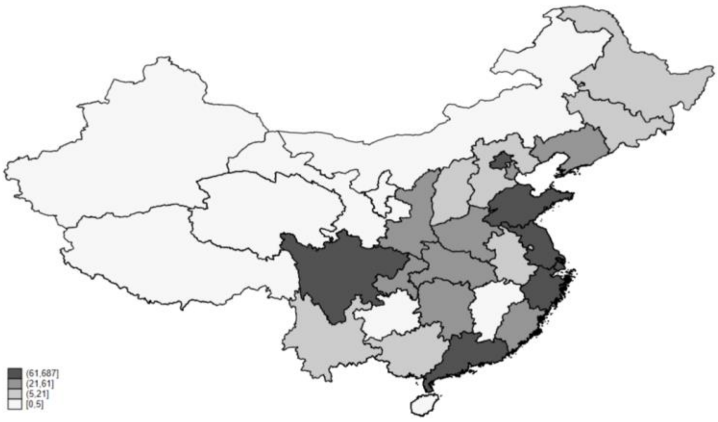
	Level		First Difference		Second Difference	
Variable	Inverse normal	p-value	Inverse normal	p-value	Inverse normal	p-value
CO2 Emissions	48.8607	0.8475	-5.0671	0.0000	-	-
CO2 Emissions Intenisty	0.4776	0.6835	-11.3528	0.0000	-	-

Ho: Panels contain unit roots

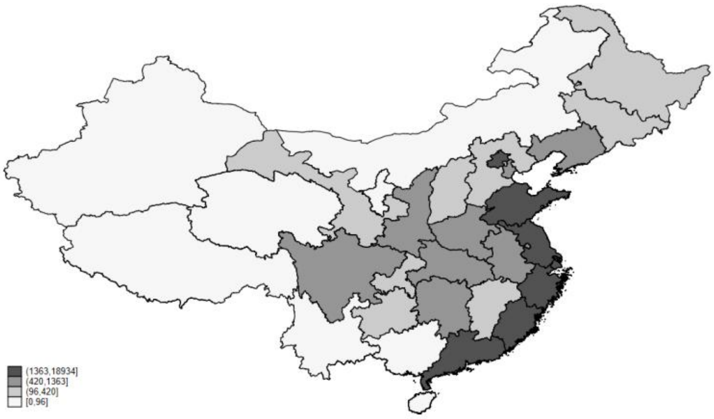
Tests include time trends

Appendix 3: Electronics Patents

1999

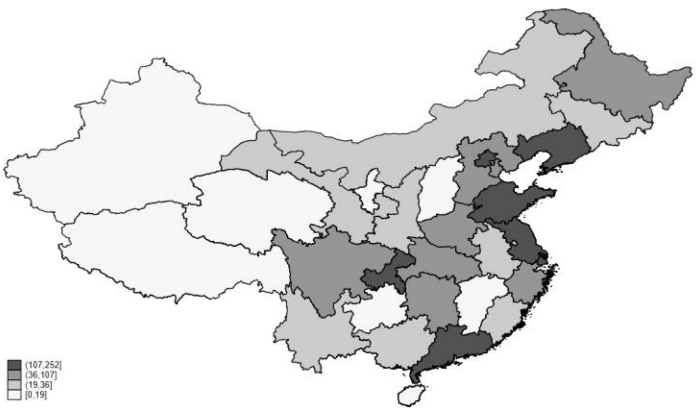


2009

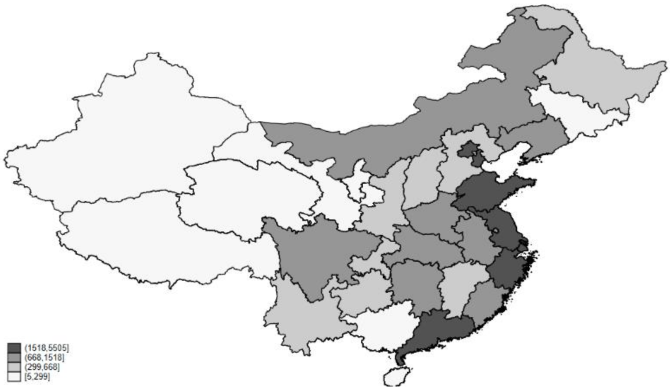


Appendix 4: Chemicals Patents

1999

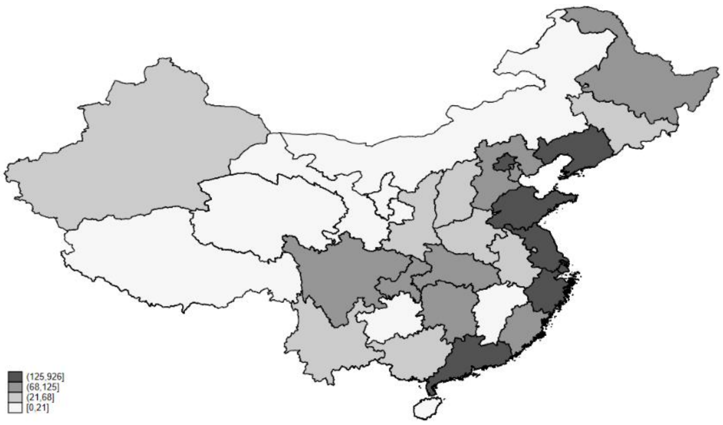


2009



Appendix 5: Other Manufacturing Patents

1999



2009