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# Credit constraint, financial development, and pollution emissions: evidence from China

Thomas Pernet-Coudrier

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**UNIVERSITE PARIS I PANTHÉON SORBONNE UFR de l'École  
d'Économie de la Sorbonne**

Laboratoire de rattachement : Centre d'économie de la Sorbonne (UMR 8174)

**THÈSE**

Pour l'obtention du titre de Docteur en économie

Présenté(e) et soutenu(e) publiquement

le 24 octobre 2022 par

**Thomas PERNET-COUDRIER**

**Titre de la thèse**

Credit constraint, financial development, and pollution emissions: evidence from China

*Sous la direction de Mme Mathilde MAUREL (Directeur de recherche) &  
CHEN Zhao (Directeur de recherche)*

***Membre du Jury***

PONCET Sandra Directeur de recherche, Centre d'Economie de la Sorbonne CNRS -  
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sciences économiques CERDI

FAN Haichao, Associate professor, Fudan University



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## Résumé

Les conséquences d'un développement économique non maîtrisées et démesurées ont des effets irréversibles sur le climat et l'environnement comme il est possible de voir en Chine. L'industrialisation massive de la Chine exacerbée par l'adhésion à l'OMC en 2001 a aggravé un écosystème déjà très fragile. La pollution de l'air, des sols, de l'eau, la déforestation, et d'autres aléas climatiques poussent la Chine au bord d'une crise environnementale sans précédent. Au cours de cette thèse, nous nous sommes intéressés au rôle du développement financier et des politiques environnementales menées depuis 2001 sur les émissions de polluants toxiques. Alors que les contraintes de crédit qui pèsent principalement sur les entreprises privées sont associées à d'avantage de pollutions, les entreprises qui ont la capacité d'utiliser leur trésorerie pour investir dans les technologies, la productivité ou les abattements de pollution vont contribuer à une réduction des émissions de pollution. Toutefois, cet effet n'est pas perceptible dans les villes ayant une part relativement élevée d'entreprises étatiques. Ces dernières ne sont pas soumises aux contraintes de crédit car l'Etat fournit du crédit en abondance, et les objectifs sont d'ordre économiques plus qu'environnementales. Par ailleurs, la situation du marché du crédit a connu des bouleversements majeurs en Chine au cours des années 2000. La dérégulation du marché bancaire et la création de banques commerciales ont permis d'injecter du capital dans l'économie, principalement à destination du secteur privé. Ainsi, le développement financier a conduit à une réduction des émissions de rejets toxiques. Par ailleurs, le gouvernement chinois utilise régulièrement des politiques industrielles pour promouvoir ou décourager le développement de certaines industries. En date, les rabais de TVA à l'exportation ont pour objectif de réduire les exportations de produits énergivores. Notre analyse a soulevé que les entreprises ne vont pas se lancer dans une stratégie de montée en gamme lorsqu'elles sont confrontées à des politiques industrielles contraires aux objectifs environnementaux.



## **Summary**

As has been observed in China, the inexorable ramifications of uncontrolled and excessive economic development have irreversible effects on the climate and the environment. China's large-scale industrialization, coupled with its decision to join the WTO in 2001, has exacerbated the trenchant problems of an already very fragile ecosystem. China is being pushed to the brink of an unprecedented environmental crisis by a plethora of challenges, air, soil, water pollution, deforestation, and other climate hazards. During this thesis, we have been interested in examining the role of financial development and environmental policies on pollutant emissions since 2001. While the credit constraints that weigh mainly on private companies are linked to increased pollution, companies that can utilize their internal finance to invest in technology, productivity, or pollution abatement equipment contribute to a reduction in pollution emissions. However, this effect has not been observable in cities with a relatively high share of state-owned enterprises. SOEs are not subject to credit constraints because the government provides them credit abundantly, and the objectives are more economical than environmental. Moreover, China's credit market underwent major upheavals during the 2000s. The deregulation of the banking market and the creation of city commercial banks made it possible to inject capital into the economy, mainly for the private sector. Therefore, it can be surmised that financial development has resulted in a reduction of toxic emissions. In addition, the Chinese government regularly uses industrial policies to promulgate or stymie the development of specific industries. To date, export VAT rebates aim to reduce exports of energy-intensive products. Against this backdrop, our analysis has shown that domestic companies will not embark on a product upgrading strategy upon being confronted with industrial policies that run counter to environmental objectives.

## **Mots-clés**

Chine – émissions de pollution – contraintes de crédit – développement financier  
financement interne – environnement – politiques environnementales – rabais de TVA

## **Keywords**

China – pollution emissions – credit constraint – financial development  
internal finance – environment – environment regulation – VAT rebate

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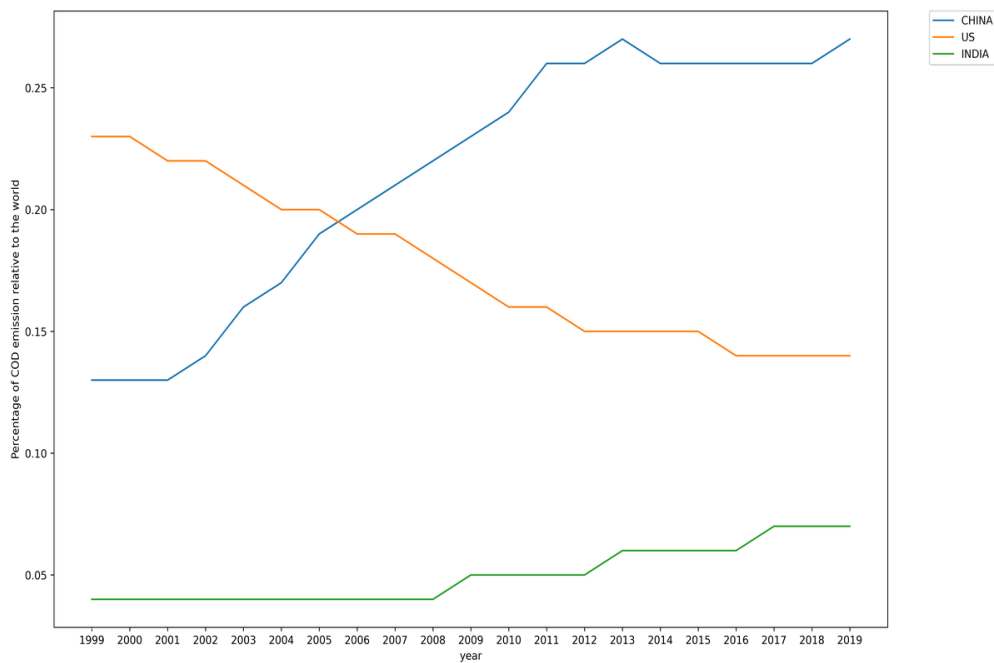


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# Introduction

The rapid industrialization expansion of China has become more than alarming in recent years. Mass industrialization fueled by carbon-intensive industries pushed China to the edge of an unprecedented environmental crisis. The development path taken by China, combined with a lack of solid political commitment toward the environment, jeopardized the overall ecosystem. Water scarcity, soil contamination, forest depletion, and air pollution are just a few of the challenges that will become increasingly difficult to cope with in the coming years with the expansion of climate change.

**Figure 1: World share of COD emissions in China, the US and India**



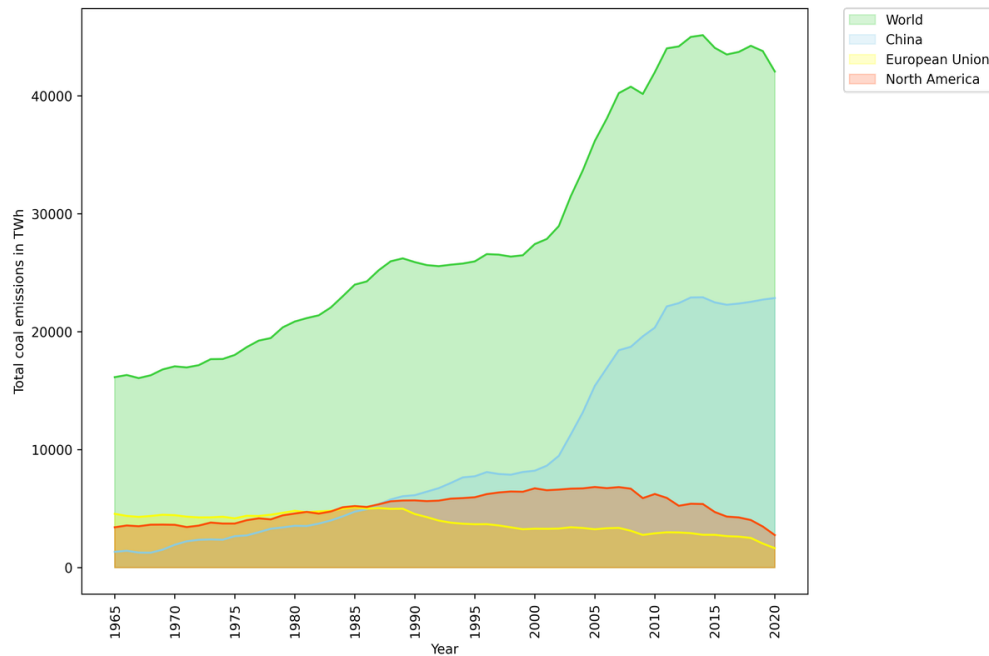
**Source:** <https://ourworldindata.org/co2-emissions>

The environmental consequences that originated in China are not bound within the country’s borders. Today, China is the world’s largest emitter of chemical oxygen demand (COD),<sup>1</sup> accounting for about 27% of the world’s total emission in 2019, with a yearly

<sup>1</sup>Chemical oxygen demand is defined “as the amount of oxygen equivalents consumed in the chemical oxidation of organic matter by strong oxidant” (Hu and Grasso 2005). COD is often used to measure water, wastewater, and hazardous waste pollutants.

average of 4% (or stabilized at 1% after 2011) as plotted in figure 1. China’s unremitting appetite for coal is out of reach. Developed economies such as the European Union or the United States have reduced their reliance on coal extensively,<sup>2</sup> while China keeps consuming it (see figure 2) and opening mines at an unreasonable rate.<sup>3</sup> In 2020 alone, China added 41,016 new operating coal plants (see figure 3),<sup>4</sup> and there is no political commitment from the Party to disengaged in ending support for the fossil fuel domestically.

**Figure 2: Total coal emissions in China *versus* developed economies**



**Source:**

<https://ourworldindata.org/grapher/coal-consumption-by-country-terawatt-hours-twh>

China’s environmental challenges are nothing new, and to understand the origin of the problem, we need to go back to the early stage of the economic transition. Since the opening

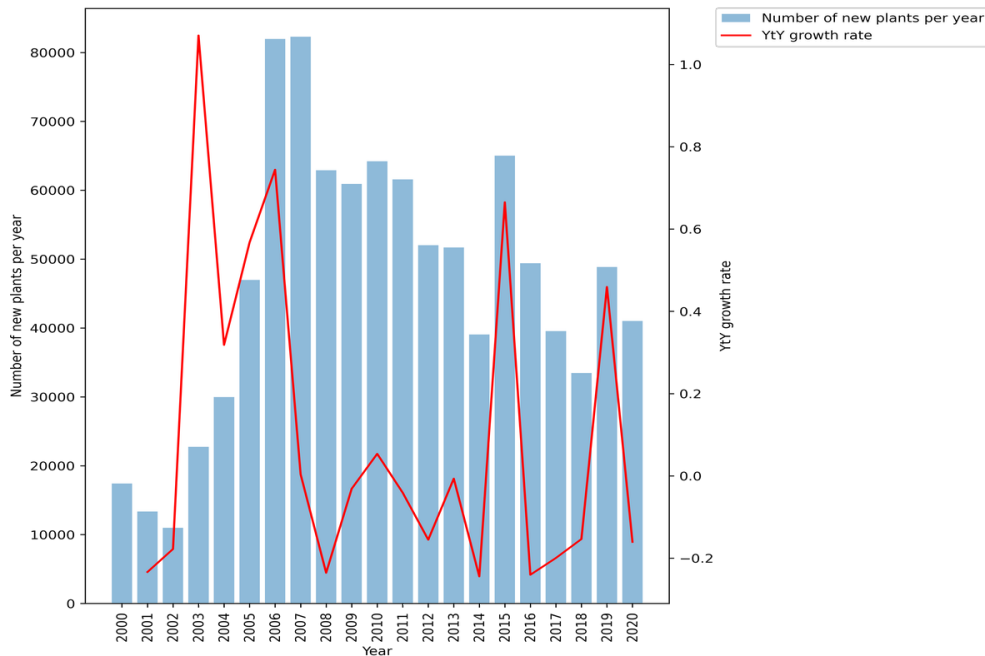
<sup>2</sup>The total coal consumption, measured in terawatt-hour (TWh), of the European Union, is about 3% in 2020, 6% for north America and 54% for China.

<sup>3</sup>As stated by the Global Energy Monitor, a research group, China is operating 66 mines overseas (see <https://globalenergymonitor.org/projects/global-coal-plant-tracker/tracker/>). However, during the 2021 UN General Assembly in New York, Xi Jinping pledged to end the financing of new coal power plants overseas which has the potential to impact up to 44 projects in various stages of development. Source: <https://www.ft.com/content/1c2d592e-2a63-4afd-bda4-69cb406c9d86>

<sup>4</sup>Source: Global Energy Monitor. <https://docs.google.com/spreadsheets/d/1W3pt5FhqitHwbVWvvgfRr0S6QfqfOuea9ptMlxp5M/edit?usp=sharing>

of China in 1978, the economic growth has grown at an astonishing pace, leading to more prominent energy consumption. To cope with the energy needs, China produces 80% of electricity from coal-fired plants (IEA: World Energy Investment 2019), which generally pollutes more than other fuels. Another reason for the relatively high emission is the use of small and medium inefficient coal-fired plants. The reliance on coal has been exacerbated after joining the WTO in 2001 in response to the country’s export boom. Figure 4 shows a strong correlation between China’s total exports and its coal consumption, especially after 2002.

**Figure 3: Total new coal mines opening in China**

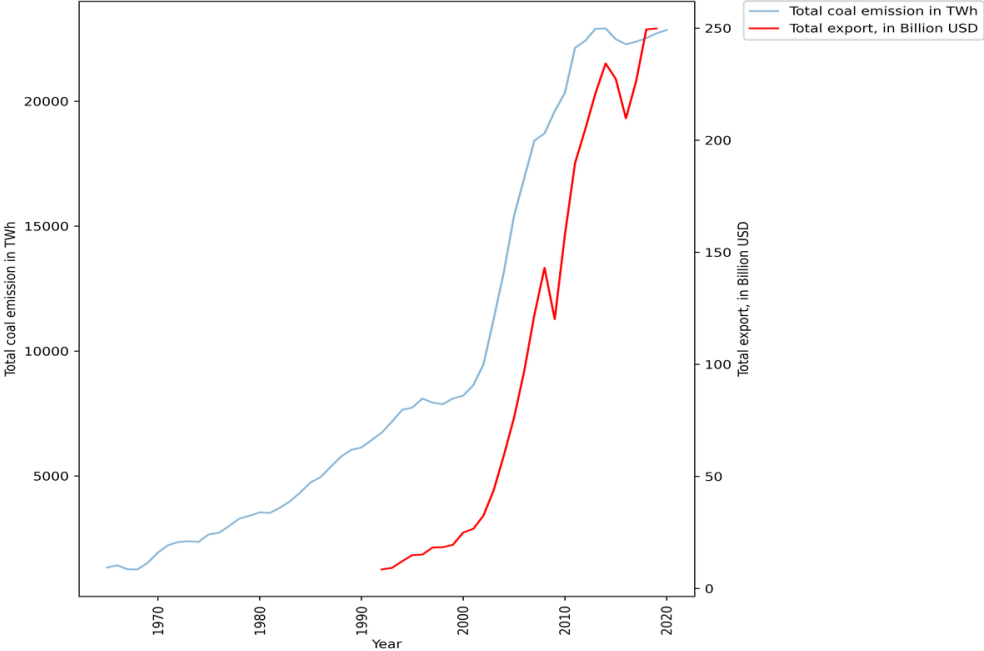


**Source:** <https://endcoal.org/global-coal-plant-tracker/>

The response from the Chinese government to the environmental issue is not new. Since 1978, a decentralized system to control and prevent pollution has been implemented. The effectiveness of the response given by the Chinese government is more questionable. Numerous environmental disasters and increases in pollution (SO<sub>2</sub>, CO<sub>2</sub>, and other primary pollutants) brought the attention of the central government to act. The damage caused

by acid rain was among the largest globally and cost around 0.7% of the GDP in early 1990 ( The World Bank 2007). In 1998, the party leaders proposed establishing a list of cities with poor environmental performances regarding sulfur emission and acid rain. The two-control-zone policy was born and is still in effect today.

**Figure 4: Yearly evolution of coal and export in China**



**Source:** Source for export: World bank and source for coal is ourworldindata

The Chinese government does not deny the severe pollution problem, and party leaders are well aware of the heavy environmental cost legacy. The real challenge is to find a balance between economic development and environmental protection. Economic growth is the only tool to achieve China’s main objective of alleviating poverty. As the people became richer, the increase in environmental awareness and discontent pushed the central government to integrate more formal environmental policies and targets to curb environmental degradation. During the 10th Five-Year Plan (FYP) (2001-2005), the first environmental target was enacted, stipulating a reduction of 10% of the total SO2 emission in 2005 from

2000 levels. The fragility and the lack of coordination/supervision of the law resulted in a total disaster. Not only did the SO<sub>2</sub> emission not decrease, but it skyrocketed like never before. The inherent problem with this law comes from the divergence of objectives between the top-level government and local government. Local governments have few incentives to pursue environmental objectives since there is no reward at the end of their political term. Following SO<sub>2</sub> policies was perceived meaningless, as China's overall development strategy remained firmly rooted in economic growth. Both career and paycheck were conditional on social objectives such as employment or economic performance like growth rate. Failure to meet one of those objectives had more severe consequences than a failure on the SO<sub>2</sub> target.

Acknowledging the failure, the central government decided to change its approach from top-down to bottom-up. In the 11th FYP, the target was broken down at the provincial level and made mandatory and career-related for the governors. A new ministry was created in 2007 to replace the State Environmental Protection Administration (SEPA) to give the objective more credibility. By the end of 2010, China managed to stabilize SO<sub>2</sub> emissions and, a few years later, the peak was reached.

By contrast, China's pollution level remains off the charts compared with the WHO standards. To give a concrete example, the monthly PM<sub>2.5</sub> average across the largest 50 cities in China has never been below 25 (WHO recommendation). In 2014, Premier Li Keqiang pledged to enter to war against pollution. One year later, China signed the Paris agreement, committing to reduce the country's carbon intensity by 60-65% from 2005's level by 2030. The challenge is considerable because China's appetite for energy is prevalent. There are few signs of reducing coal consumption nor a substantial reduction in air or water pollutants.

The literature has long documented the role of export, growth, and reliance on heavy

industry to explain pollution emissions or relatively poor environmental performances. However, there is a lack of literature about the role of the financial system on environmental performance.

## **Effect of misallocation of financial resources on the pollution emissions**

Chapter 1 of the thesis aims to fill the financial system and pollution emissions gap. Most recent literature disentangles the impact of trade, competition, and regulation on pollution emissions or abatement, but only a few papers focus on the financial constraint (Andersen 2017; Zhang and Zheng 2019). In the first chapter, we demonstrate that a malfunctioning financial system penalizes private firms who seek external financing, which leads to more pollution emissions through an over-investment in tangible assets. The role of banks in an economy is vital, especially for businesses, as they seek funding, typically loans, to finance their business operations. In a well-functioning credit market, banks create liquidity by lending savings to corporations after assessing the risk of default. Meanwhile, the most effective way to reduce environmental damage from economic activities is to address it by introducing environmentally superior technologies and practices, assuming that they can be financed.

Banks also require collateral from the borrower. The term collateral refers to an asset a lender accepts as security for a loan. In most cases, collateral takes the form of a physical asset, which can be easily converted to a monetary value due to its high liquidity. The primary role of the collateral is to protect the lender in case of default; that is, the loan writer can seize the collateral and resell it to minimize its loss. The collateral should be proportional to the loan size and ensure the borrower will continue to repay its debt until termination. In the meantime, corporations can use the equity market (or stock market) to



buy debt securities such as bonds.

Bonds are one of the most typical ways to increase capital in developed economies: getting money from investors now, paying an interest rate until maturation, and finally reimbursing the principal. According to the Modigliani-Miller theorem (Modigliani and Miller 1958), the financial system efficiently allocates resources regardless of the choice of financing - be it internal financing such as cash, or by borrowing money from a financial institution (banks), or by raising money through new stock shares.

The literature has extensively explored the Modigliani-Miller model to determine if a firm or an industry is financially constrained. In 1998, Rajan and Zingales (1998) came up with a methodology to overcome the previous empirical study flaws with endogeneity. The authors defined an industry's external finance dependence as the share of capital expenditure not financed with cash flows from operation. They used US data from listed companies between 1980 to 1990 for all sectors. The idea behind the external finance indicator is that if an industry is more financially vulnerable, it is more likely to face binding constraints. Another way to read this variable is to see the financial vulnerability as a reflection of the difference in each industry's technological characteristics, which is beyond individual firms' control. In a nutshell, when the external dependency is large, the industry is financially vulnerable and dependent on external financing.

In China, there is an emerging consensus that the financial system is deficient and credit constraint is prevalent in an industry dominated by the private sector. State banks dominate the market by supplying more than 60% of loans (Ping 2003) but ration the amount that flows to private firms. To continue their development and to fuel the Chinese growth, private firms had to use their internal cash flow to invest in research and development and other productivity-enhancing activities (Guariglia et al. 2011). The use of cash gave the private

firms more freedom in the choice of projects to finance. Indeed, there is mature literature explaining the limit of the credit market. Firms that are limited in their internal financing have no choice but to rely on an external lender; in the case of China, the banks. The equity market in China during our analysis (before 2010) was nonexistent (China's Market Capitalization in 2000 was less than 1 trillion vs. 13 trillion USD in 2021.<sup>5</sup>) It is worth noting that the equity market is meant to reduce adverse selection and moral hazard, thus reducing the firm's cost of external capital. By contrast, banks are not suited to bear the risk of financing innovation through research and development. Unlike the equity market, banks are relatively risk-averse, which prevents them from providing funding for innovation.

According to Stiglitz (1985), industries with a significant external financial dependency tend to under-invest in innovative projects. One of the main reasons comes from the requirement of collateral. Collateral has to be attached to a finite-monetary value that the bank can assess. However, for Berger and Udell (1990), a research and development project does not have collateral to pledge because intellectual property or pattern is complex for banks to resale and the intrinsic value has greater uncertainty than tangible assets. For Morck and Nakamura (1999), the credit market is highly biased toward conservative investments, traditionally tangible assets, and leads firms to push back against or forego innovative projects. Hence, the credit market discourages innovation and the financing of intangible assets.

Figure 5 confirms the assumption that firms in the constraint industry tend to have a larger share of tangible assets<sup>6</sup> in their books. We used the firm-level ASIF dataset to construct the share of tangible assets over total assets from 2000 to 2007. We divided the industries based on whether they are financially dependent on external financing or not. To

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<sup>5</sup>Source: <https://www.ceicdata.com/en/indicator/china/market-capitalization>

<sup>6</sup>A tangible asset is an asset with a finite monetary value and usually a physical form. Tangible assets can typically always be transacted for some monetary value through the liquidity of different markets will vary. Tangible assets are the opposite of intangible assets with a theorized value rather than a transactional exchange value. Tangible assets are the most basic type of assets on the balance sheet. They are usually the main form of assets in most industries. They are also usually the easiest to understand and value

define a constraint industry, we borrowed the values from Fan et al. (2015), which replicates the methodology of Rajan and Zingales (1998) but using Chinese data. External financial dependency is available for 29 two-digit industries. We took the median value (-0.47) to split the industries equally between constrained and not constrained. The blue line represents the share of tangible assets for the constraint sectors and the red line for the unconstrained ones. The evidence is clear that industries that rely on external financing have a larger share of tangible assets than their counterpart.

**Figure 5: Share of tangible assets in constraint and not constraint industries**



**Source:** ASIF firm-level data and authors' own computation

The literature is not ambiguous on the bias toward tangible assets for industries relying on external financing. However, there is little evidence of the impact of tangible assets on pollution emissions. One exception is Andersen (2017) who proposes a model where credit constraint distorts the optimal asset allocation (tangible *versus* intangible).<sup>7</sup>The bias toward

<sup>7</sup>An intangible asset is an asset that is not physical in nature, such as a patent, brand, trademark, or

tangible assets typically stems from the fact that banks can claim collateral while intangible assets do not have "calculable" value.

Andersen extends the credit-constraint/tangible assets nexus by showing that tangible assets positively correlate with pollution emissions. More recently, Zhang and Zheng (2019) explored the effects of financial constraints on pollution abatement at the firm level in China. The authors showed that the financial constraint obstructs air pollution abatement.<sup>8</sup> Using the data from the Chinese Environmental Statistical Database,<sup>9</sup> we show in figure 6 the evolution of SO<sub>2</sub> and asset tangibility over total assets from 2000 to 2007. Both lines evolve in the same direction over time, showing a potential relationship between the effect of tangible assets on SO<sub>2</sub> emissions.

## **Effect of Soft Budget Constraint and environmental policy on the pollution emissions**

The financing problem does not affect all firms in China, and typically private firms are the most impacted. The Chinese government has always favored state-owned enterprises

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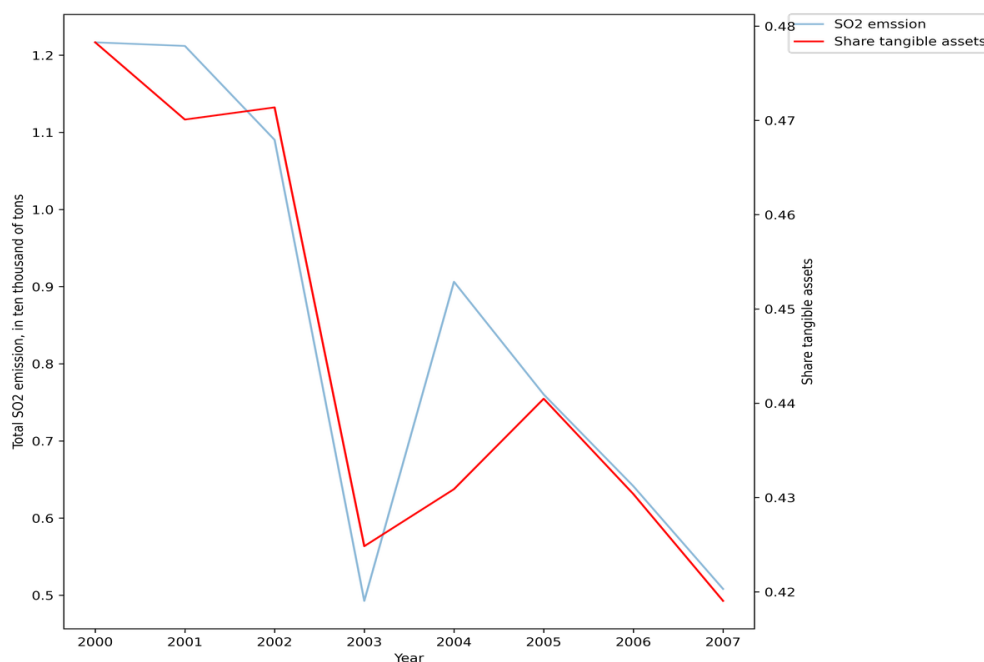
copyright. Businesses can create or acquire intangible assets. An intangible asset can be considered indefinite (a brand name, for example) or definite, like a legal agreement or contract. Intangible assets created by a company do not appear on the balance sheet and have no recorded book value.

- An intangible asset is an asset that is not physical in nature, such as a patent, brand, trademark, or copyright.
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<sup>8</sup>According to the OECD, pollution abatement refers to "technology applied or measure taken to reduce pollution and/or its impacts on the environment. The most commonly used technologies are scrubbers, noise mufflers, filters, incinerators, wastewater treatment facilities and composting of wastes."

<sup>9</sup>Since 1980, the MEP has established a system of environmental statistics to collect data on environmental pollutants and wastes. This database covers all provinces, with plants considered as more important enterprises that are under direct monitoring of the MEP.

**Figure 6: Total SO2 emission *versus* share of tangible assets**



**Source:** ASIF firm-level data and SO2 emission data comes from the Ministry of Environmental Protection

when it comes to critical industries (natural resources, telecoms, banking, healthcare, etc.) and attaining social objectives, even going so far as to bail them out when needed. The latest point is the soft budget constraint (SBC), a concept developed by Kornai in the early nineties (Kornai 1993). The soft budget constraint occurs when the credit contract between two parties is not enforced, and the bailer assists the firm in great financial trouble without real hope of repayment of the debt. There is plenty of evidence proving the soft budget constraint is verified for state-owned firms, while the opposite circumstance holds for private firms: credit constraints. The soft budget constraint remains applicable in recent years; international rating agencies and fund managers have long criticized China's artificially high corporate credit scoring and low default rates, pointing to a lack of transparency and the assumption that the government will bail out struggling companies.<sup>10</sup>

The SBC concept sees a straightforward application to the objective of sustainable

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<sup>10</sup>Financial Times, Corporate Bond Downgrades by China Rating Agencies Triple, May 17th, 2021.

growth: under rational expectations of being bailed out, public (SOE) or private organizations will not be motivated to reach the objective of reducing pollution. The second chapter deals with the opposite effect of environmental policy enacted by the central government and the lack of applicability to the local level, partly due to the bailout of state-owned enterprises. More specifically, what external circumstances beyond the SBC mattered to realize such environmental objectives in China? Evidence suggests that the cadre rotation system, which transfers officials to new positions every three to four years, may be why short-term gains, including the extraction of rents from local polluting firms, could be prioritized over long-term ones. Studies have shown that cities with more educated mayors reach the environmental Kuznets curve turning point at lower per capita income levels (Zheng et al. 2014).

Last but not least, holding higher positions than local officials, senior managers of state-owned firms perceived themselves as above the local law. As a result, some cities are populated by SOEs that violate environmental regulations while simultaneously generating jobs essential to local mayoral performance evaluations. The chapter will revisit the issue of the cities' behavior and how they react to environmental regulation.

Chinese policymakers decided to take the environmental issue seriously after the sulfur dioxide (SO<sub>2</sub>) peak hurt the country in 1995. In no less than three years, the officials in Beijing proposed and ratified a law regulating SO<sub>2</sub> emissions. In 1998, the central government implemented the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone policy, abbreviated as the Two Control Zone (TCZ) policy, to limit pollutant emissions. While the regulation of SO<sub>2</sub> emissions was initially designed to be implemented at the national level, the State Council subsequently chose 175 TCZ cities with deplorable environmental records to engage more effort. Three selection criteria were established according to pre-regulation environmental performance. A city was scrutinized if the average annual ambient

SO<sub>2</sub> concentration exceeded the national class 2 standard (0.06 mg/m<sup>3</sup>), if the daily average ambient SO<sub>2</sub> concentration exceeded the national class 3 standard (0.25 mg/m<sup>3</sup>), or if the city experienced significant SO<sub>2</sub> emissions.

The chosen 175 cities are primarily concentrated in two areas: northern China, owing to heavy reliance on coal to power heating systems, and southern China, where the urban-industrial centers emit substantial air pollution and are the sources of severe acid rain. TCZ cities cover 1.09 million square kilometers in 27 provinces, accounting for 11.4% of the whole of China's territory. At the national level, the objectives were as follows: SO<sub>2</sub> emissions were expected to decline successively in 2000 and 2010, and TCZ cities were assigned a special responsibility of achieving the national class 2 standard of 0.06 mg/m<sup>3</sup>. The quota of SO<sub>2</sub> emissions set by the central government in 2000 was to not exceed 24.6 million tons—compared with 23.7 million tons in 1997—and emissions in 2010 were expected to decline even more than in 2000. In 2001, policymakers strengthened the national consistency of the environmental policy, which was called the control policy in the 10th FYP (2001–2005). China's entry into the World Trade Organization in 2001 launched a process of massive industrialization, economic growth, and poverty reduction, which was at odds with the achievement of the objective of stricter pollution controls.

The consequences of the lack of coordination and the focus on economic growth from local governments led to a historical peak of SO<sub>2</sub> emissions in 2005, which rose by a factor of 45% from 2002 to 2005. The poor results of the environmental policy were attributed to the design of the policy itself. Its main flaw was that the objectives set at the national level were not restrictive enough at the local level. As a result, economic growth was heavily emphasized by the central government, which did not provide local municipalities with incentives to pursue economic growth and pollution control at the same time. Those objectives frequently turned out to be contradictory and could not be achieved simultaneously (Barbier and Burgess 2019;

Brajer et al. 2011; Lee and Oh 2015).

In 2006, the central government reconsidered its strategy, changing from a top-down to a bottom-up approach. Echoing the academic literature, which has provided extensive research on the motivations of bureaucrats to implement this particular policy, the two main differences introduced in the 11th FYP (2006–2010) from the previous FYP (2001–2005) were the formulation of clear pollution reduction guidelines for the Chinese provinces and the introduction of an environmental target-based evaluation system for the promotion and career advancement of local officials. The target-based evaluation system aimed to promote efforts toward meeting the objectives considered to be priorities by the central government. It provided a tool for measuring the success of the local administration, making them accountable equivalently for success and failure. The threat imposed by Beijing forced the mayors and party secretaries to adhere to the national policy. Zheng et al. (2014) emphasized that the new incentives are largely responsible for the success of the new regulation. In 2006, the Chinese government decided to break the national SO<sub>2</sub> target down to the provincial level. The new policy sets bold objectives of SO<sub>2</sub> reduction based on the 2005 SO<sub>2</sub> level. Larger provinces' pollution emitters in 2005 were attributed to the larger reduction in 2010.<sup>11</sup> Figure 7 shows the maximum amount of SO<sub>2</sub> tolerated in 2010 for each province in China (blue bar), and the reduction achieved based on the 2005 level (red bar). For instance, in 2005, Shandong was the largest polluter, with a total of 200.3 thousand tons of SO<sub>2</sub> emitted. In 2010, Shandong's maximum amount could not exceed 160.2, or a reduction of 40 thousand tons.

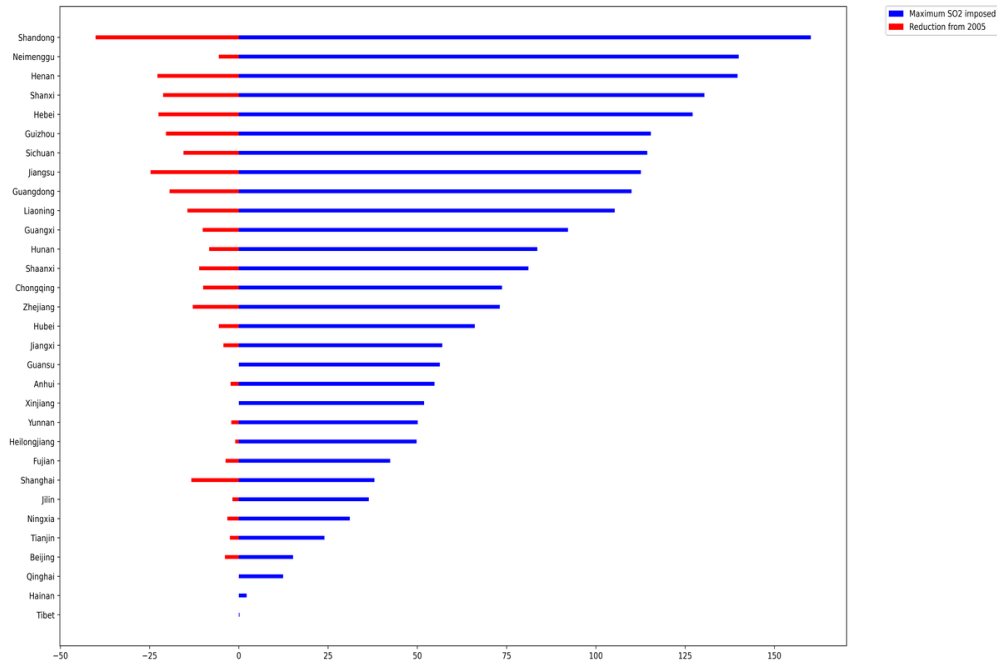
Answering questions about the impact of the lack of an efficient financial system on the environment requires data about emission pollution. The Chinese environmental data

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<sup>11</sup>The official statement is available here.



Figure 7: FYP SO2's provincial targets



Source: MEP Dataset

is extraordinarily detailed and covers most industries across the country. Since 1980, the Ministry of Environmental Protection (MEP hereafter) has implemented a system to collect environmental protection and waste data. The data is collected from plants considered important polluters and under the scrutiny of the MEP. Firms are required to self-report their emission of pollutants annually, and the MEP conducts monitoring and surprise inspections to ensure the firms are diligently reporting the data. In case of poor or incorrect reporting, the firm faces severe consequences.

It should be noted that this pollution dataset is collected at the manufacturing plant level. In other words, each firm in the dataset represents one manufacturing plant in one city with detailed plant-level emission data. In summary, the dataset provides information on the major pollutants in China; namely sulfur dioxide, wastewater, soot, and COD. In chapters 1 and 2 of this thesis, we use this dataset at the city-sector level from 1998 to 2007. One of the main reasons we use the city-sector level is that this dataset is extremely

sensitive, and sharing firm-level data is not easily feasible.

The financial system is characterized by the difficulties in China in obtaining credit from the banks for the private sectors (i.e., credit constraints) and the favoritism toward state-owned enterprises regarding financing. Private firms manage to cope with the strong domestic and international demand by using their internal finance<sup>12</sup> as documented by Guariglia et al. 2011; Chen and Guariglia 2013 or Héricourt and Poncet (2009). Little evidence, however, evaluates the type of financing on pollution emissions. Andersen (2017) provides a theoretical framework to explain the relationship between credit constraint and pollution emission. The channel in which credit constraints positively impact pollution is the asset distortion toward tangible assets. We extended his analysis by exploring the variation of internal finance to explain the change in SO<sub>2</sub> emissions in China from 2001 to 2007.

On the one hand, we relied on China's most extensive environmental dataset to construct the city-industry-year SO<sub>2</sub> emissions. On the other hand, we construct the internal finance (cash flow and liquidity) from the most comprehensive firm-level dataset in China, the ASIF dataset collected by the National Bureau of Statistics of China (NBS). Our results confirm Andersen (2017)'s hypothesis that tangible asset positively correlates with pollution emissions. The constrained firms have few options to borrow money from the credit supplier because the latter requires collateral to hedge the credit, which avoids investment in research and development of innovative projects. Then, we demonstrate that the availability of cash reduces the SO<sub>2</sub> emission with a stronger effect on private and domestic firms. A more thorough investigation is conducted in the second part of the chapter to explain the lack of correlation between state-owned enterprises and emissions of pollution.

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<sup>12</sup>According to the theory of capital structure, internal financing is the procedure of a firm using its profits or assets as a source of capital to fund a new project or investment. The opposite of internal finance is external finance, which relates to loans, bonds, or equity issues.

The presence of a large share of state-owned enterprises makes reducing pollution and achieving the environmental objectives set by the central government difficult. Our calculation shows that the reduction in SO<sub>2</sub> emission reached approximately 5% of the average emission of polluted sectors after 2006 in cities not dominated by state-owned enterprises. We interpret the results as pointing to evidence of Chinese SOEs' ongoing soft budget constraints. Moreover, we investigate four mechanisms under which the soft budget constraint operates.

First of all, we try to determine the underlying regulatory non-compliance: the overlapping (or not) of "Two Control Zone" (Special Policy Zone, Coastal) cities wherein environmental (growth) policies are prioritized. The results suggest that firms in Two Control Zone cities have a stronger reaction to environmental regulation and that the TCZ and the FYPs are complementary under the assumption of a larger share of private firms.

Secondly, we question whether industrial concentration leads to different firms' behavior. Large companies are in a stronger bargaining position and can more easily pursue their objectives and influence local authorities concerning the effective enforcement of environmental regulation. Third, we make an effort to compute the Kuznets curve<sup>13</sup> along which the relationship between pollution and economic growth is negative. The absence of a reaction to regulation is specific to SOE-dominated cities and can be interpreted as symptomatic of the SBC.

We study the regulation-induced adoption of cleaner technologies by polluting firms, enhancing productivity, and lowering SO<sub>2</sub> emissions. There are two possible opposite effects

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<sup>13</sup>The environmental Kuznets curve (EKC) assumes that there is a (non-linear) relationship between various pollutants and per capita income. In the early stages of economic growth, the emissions of pollution increase, and beyond a per capita income threshold, it declines. The threshold is different for each type of pollutant. The trend looks like an inverse-U shape indicating that economic growth leads to environmental improvement at a high-income level.

between pollution abatement and productivity. First, a positive impact is likely if innovation aims at producing at a lower cost, allowing companies to employ fewer inputs and less dirty energy per unit of output. By imposing a strict, lower limit on SO<sub>2</sub> emissions, the new regulation forces firms to upgrade or leave the market. Second, under the compliance cost theory, an adverse effect is not out of the question. If the cost of environmental regulation impedes a productivity improvement, it results in a decline in industrial performance. Enterprises' environmental protection cost forces them to bypass innovation and productivity improvement investments. However, such mechanisms may work only for private firms. A large body of literature shows that Chinese SOEs report weaker economic performance and lower total factor productivity (TFP). Overall, the results suggest that policy-induced technological improvement holds only for SOEs located in TCZ cities, wealthier cities, and lesser cities with lower industrial concentration levels.

Finally, three mechanisms are behind these significant results. First, internal finance availability reduces the bias towards tangible assets. A growing literature analyzes the extent to which the availability of internal sources of financing affects the firms' investing in fixed assets, inventory, or R&D (Chen and Guariglia 2013; Fazzari et al. 2000; Rajan and Zingales 1998). According to this literature, firms with more internal finance are less likely to invest in tangible assets and more likely to use their cash flow to fund technological innovations and R&D. From the supply side, banks are reluctant to finance intangible assets because the latter is not considered to be valuable collateral (Brown and Petersen 2009). The results indicate without doubt that the availability of internal finance distorts the allocation of assets within firms. We find a positive association between internal finance and R&D expense and a negative relationship with external finance (i.e., credit supply) simultaneously. Likewise, asset tangibility and internal finance estimate manifest an unequivocal negative association.

Secondly, TFP significantly reduces SO<sub>2</sub> emission, which is enhanced when firms have more internal finance. The literature has documented the decrease in polluting emissions induced by TFP, which means that more productive firms are more resource efficient (Brown

and Petersen 2009; Fazzari et al. 1988; Li et al. 2018). Overall, our results suggest that firms generating enough cash flow manage to improve their productivity through different innovative investments and technology adoption. This results in a TFP-induced decrease in the emission of SO<sub>2</sub>.

Thirdly, the availability of internal finance contributes to a decrease in the emission of pollutants through the purchase of pollution abatement equipment. Using the MEP data (Wang and Chen 1999) reports that the sources of investment in abatement gradually switched from subsidies to the firm's profit. Insofar the access to external finance is limited for private firms and subsidies are drying up, we investigate if internal finance can make the acquisition of pollution abatement equipment affordable. Our results suggest that companies better endowed with internal finance are more likely to purchase pollution abatement equipment. In line with the results of Fan et al. 2021, larger firms complying with environmental policy enjoy preferential loan interest rates, while smaller companies have no option but to reduce the product size when they cannot comply with the regulation. We find that smaller firms are more likely to invest in pollution abatement equipment through their cash flow, unlike larger firms which are less constrained.

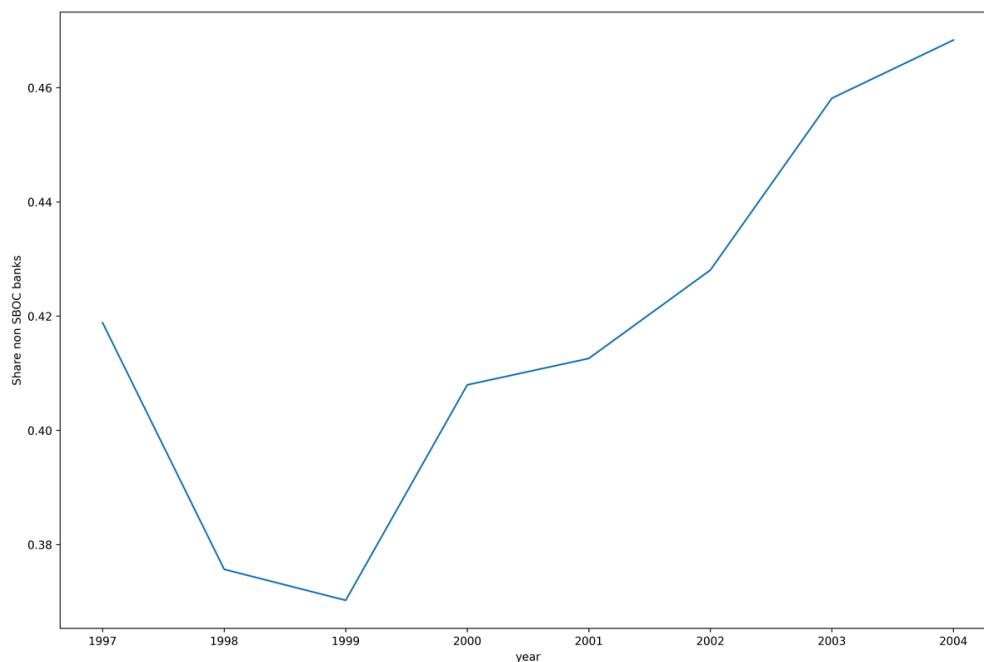
## **Effect of financial development on pollution emissions**

In the first two chapters of the thesis, we demonstrate that the misallocation of financial resources is detrimental to the environment. On top of that, we document the underlying mechanisms: asset distortion, credit constraint, and soft-budget constraint, among others. In the third chapter of the thesis, we take a different approach to elaborate on potential solutions to balance finance and environmental performance. More specifically, we evaluate if improving the banking sector's efficiency contributes to reducing the emissions of toxic pollutants.

We previously saw that not all sectors can use internal finance (cash, mainly) to invest in better resources to enhance productivity or purchase pollution abatement systems. Those sectors have few other options than to raise money through a loan. In a context like China, where the banking sector rations the supply of credit, deregulation is the only way to increase money flow into the private sector. China started to open the banking sector in 1994 with a stronger push by the government after 2000. Banking reforms initiated in 1994 sought to separate policy banks (i.e., state-owned banks) from commercial banks. The four major state-centered banks in China (namely Industrial and Commercial Bank of China, China Construction Bank Corporation, Agricultural Bank of China, and Bank of China) issued about 75% of the total credit supply, mostly directed toward the state-owned enterprises. Since loan recipients are mainly SOEs, which enjoy a soft budget constraint, the four main banks have a strong share of non-profitable loans (Ferri and Liu 2009) compared with joint-venture equity banks and city banks. Recognizing the four State-Owned Commercial Banks' (SOBC) apparent failure to allocate capital efficiently, the Chinese government implemented substantial banking sector restructuring. It started in 1994, when the government allowed more players, primarily with city commercial banks owned by local governments, firms, and private shareholders. It continued in 1996 with the apparition of foreign banks. The market penetration of those banks was gradual, as shown by figure 8. The market share of non-SOBC was at its lowest in 1999 and has kept growing.

The successive introduction of waves of new types of financial institutions undeniably increased competition and spurred efficiency, especially in credit allocation. Not surprisingly, the rate of NPL decreased subsequently by the end of 2002 (as a response to the SOBCs' decrease in market share). The liberalization and reform of the banking system - transforming the urban credit cooperative into commercial banks, allowing for the introduction of foreign banks, limiting the state-centered management system, etc.- led to an improvement

**Figure 8: Share of non-SBOC loan's supply over total loan**



**Source:** Almanac of China's Finance and Banking

of China's financial landscape (better profitability and less risk).

Banking openness has proven effective at stimulating economic growth, productivity, and export and improving resource allocation across industries. In chapter 2, we emphasize the consequence of the financial system reforms on environmental performance. Recent research in developed economies found evidence of a link between financial development and the environment. At least three channels might be at stake to understand how a well-functioning financial resource allocation affects a firm's environmental performance.

First of all, more credit supply combined with a better credit allocation can reduce pollution by increasing investment in pollution abatement (Goetz 2019). Indeed, cheaper long-term financing drives the firm to invest in capital-intensive pollution abatement systems. Secondly, credit availability allows for greater investment in productivity-enhancing activities or upgrading existing capital. In both ways, it raises production efficiency, reducing energy

consumption. More precisely, when a firm has access to external finance, internal constraints become less of a burden, potentially providing a financing alternative to invest in technology or equipment to increase productivity.

Finally, the third channel through which a relaxation of the credit constraint can reduce pollution emission is drawn from Andersen (2017)'s model. Financial constraints distort the asset mix, which hampers the acquisition of intangible assets. Tangible assets are positively linked with the emission of SO<sub>2</sub>, asserting that financial constraint is detrimental to the environment.

The primary objective of chapter 3 is to evaluate whether improving credit conditions (banking deregulation and financial development) benefits the environment in sectors characterized by different levels of financial vulnerability. Emissions of pollutants are a function of a firm's performance and innovation, while the lack of external funding (in vulnerable sectors) has been proven to be a detriment to growth, export and, more importantly, productivity and innovation. We assume that relaxing the credit constraint (with deregulation and competition) leads firms to take a step forward in innovation and the production or purchase of pollution abatement systems, reducing the per-unit level of toxic emission.

We used two proxies for financial development and deregulation. We exploited the variation of external credit supply across different provinces and four cities in China, computed as the share of the long-term loan normalized by the province GDP to estimate the financial development. Then, we used two proxies to capture bank deregulation computed at the city level. Our first proxy is measured by the number of city commercial bank branches in year  $t$  in city  $c$ . Our second proxy is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. The point is that a decrease in the ratio over time implies more competition in the banking sectors and more credit supplied to the private sectors.



Our results show that improving the market condition is more beneficial for sectors in financial distress because they cannot rely on internal finance to sustain their business. Indeed, an inflow of credit in the market has a more substantial negative effect on the sectors' pollution in financial distress. It can be explained by the fact that loosening the credit allocation and allowing more players to finance the private sectors facilitates investment in research and development or pollution abatement equipment, reducing sectoral emissions.

We exploited the richness of the MEP dataset to investigate the underlying mechanisms between financial development and pollution emission. Firstly, the purchase of pollution abatement equipment can be used to reduce emissions. Secondly, investment in better technology, and lastly, an improvement of the asset mix or a reduction in production, can also affect pollution emissions.

Financial development is characterized by cheaper access to credit and a larger inflow of money, as explained by Chaney (2016). In both cases, more credit supply or easier access to a loan can be used to purchase pollution abatement equipment or invest in superior technology. In this context, a firm can choose to invest in capital-intensive pollution abatement or technology adoption. It is, so far, unclear which effect dominates from a theoretical point of view and if either effect has a statistical impact on emissions. The effect is ambiguous because cheaper access to finance may lead firms to invest more in pollution abatement equipment. However, if a firm decides to invest in technology adoption that spurs productivity, it reduces energy consumption due to a per unit cost-saving. The technology-adoption channel reduces pollution emission, which to some extent minimizes the incentive for a firm to purchase pollution abatement equipment. In the context of developed economies, Goetz (2019) shows that an exogenous financial shock positively affecting the access to finance led US firms to cut pollutant discharge through pollution abatement, while in a developing economies context, Gutiérrez and Teshima (2018) demonstrates that the reduction of pollution emission comes from the technology-adoption mechanism. Firms can reduce their emissions through

a cost-saving process improvement using technology upgrades or better management practices without purchasing pollution abatement equipment (Gutiérrez and Teshima 2018). To measure the improvement in plants' general technology, we follow Gutiérrez and Teshima (2018) and divide the total use of industrial water over sales. The variable suggests that industries with lower values have a better production efficiency.

The results show that more financially-constrained firms do not contribute to the pollution emission change by purchasing pollution abatement equipment. One plausible explanation is that managers de-prioritize environmental abatement when facing financial constraints. Acquiring such equipment does not affect productivity or improve sales. Instead, it adds an incremental cost of production (i.e., more fixed costs). Specifically, the price of pollution abatement equipment is high and potentially beyond reach for constrained or small firms.

Another plausible explanation can originate from the lack of environmental law enforcement. Recent studies in China (Chen et al. 2018; He et al. 2020) and in the US (Evans and Stafford 2019; Goetz 2019; Karpoff et al. 2005; Shapira and Zingales 2017) have documented the role of environmental compliance in a firm's behavior. Suppose environmental law enforcement is not strong and, to some extent, the likelihood of receiving a fine (or a modest fine) is low. In that case, a firm does not have much incentive to invest heavily in pollution abatement equipment. Our results demonstrate that such a purchase occurs under a very specific policy; firms comply only when they face enough credible sanctions from the regulator and acquire pollution abatement equipment that is explicitly in line with the policy's objective. In the case of TCZ cities, where the objective is to reduce emissions of SO<sub>2</sub>, firms follow suit by investing in equipment categorically designed to reduce this type of toxic emission without necessarily considering other emission-reduction equipment for other pollutants.

Our second mechanism testing comes with estimating the technology adoption argument following an improvement of the financial condition. The results complement the findings of

Gutiérrez and Teshima (2018), showing that firms reduce their energy consumption through technology adoption following stronger bank competition. The adoption of new technology decreases emissions without investment in pollution abatement. Firms prefer to invest in new technologies because it translates into more sales. Conversely, investments in pollution abatement have no impact on sales, while they increase fixed costs.

Asset distortion can play a role in pollution emissions. Andersen (2017) built a model whereby the credit institution indirectly impacts pollution emissions. He shows that constrained firms usually finance tangible assets through a loan because banks require collateral as a security. By extension, the distortion of asset allocation toward tangible assets positively correlates with pollution emissions. By relaxing the credit constraint, firms could re-balance the type of asset they hold and invest relatively less in tangible and more in intangible. In this situation, it should reduce the emission of pollution. Another way in which relaxing credit constraints could contribute to pollution emissions was explained by Fazzari et al. (1988). He mentions that cheaper access to finance could increase both investments and production; without a change in the production process, we would see an increase in pollution emissions. The increased production scale may place greater stress on the environment as, assuming the constant technique effect, more inputs and resources are required to satisfy the increased demand.

Our results are twofold. First of all, the results support the mechanism proposed by Andersen (2017), in which constrained firms tend to invest relatively more in a tangible asset. Relaxing the constraint provides more flexibility for the firm in choosing the asset it wants to invest in, and they're more likely to invest in intangible assets. A reduction of investment in tangible assets in favor of intangible assets improves the environmental performance of firms following an increase in competition in the banking industry (i.e., banking deregulation). Secondly, it indicates that the change in the way banks are regulated does not play a role in the choice of the firm's level of output. Consequently, we can exclude the scale effect mechanism due to banking deregulation, and we confirm that adopting technology plays a

major role in reducing emissions.

## The role of industrial policy on product upgrading

The final chapter of this thesis tackles a different aspect of China's development. While the first three chapters focus on the determinant of pollution emissions from a financial perspective, this chapter introduces the role of industrial policy as a tool to motivate product upgrading under a credit constraint environment. For decades, the debt-fueled, "low-quality" growth model has characterized Chinese economic development. Officials in China are trying to transition toward more environmentally sustainable and quality growth, cutting off dirty and low-value-added products. China's growth is also driven by exports, as plotted in figure 9.

**Figure 9: Chinese export *versus* growth rate**

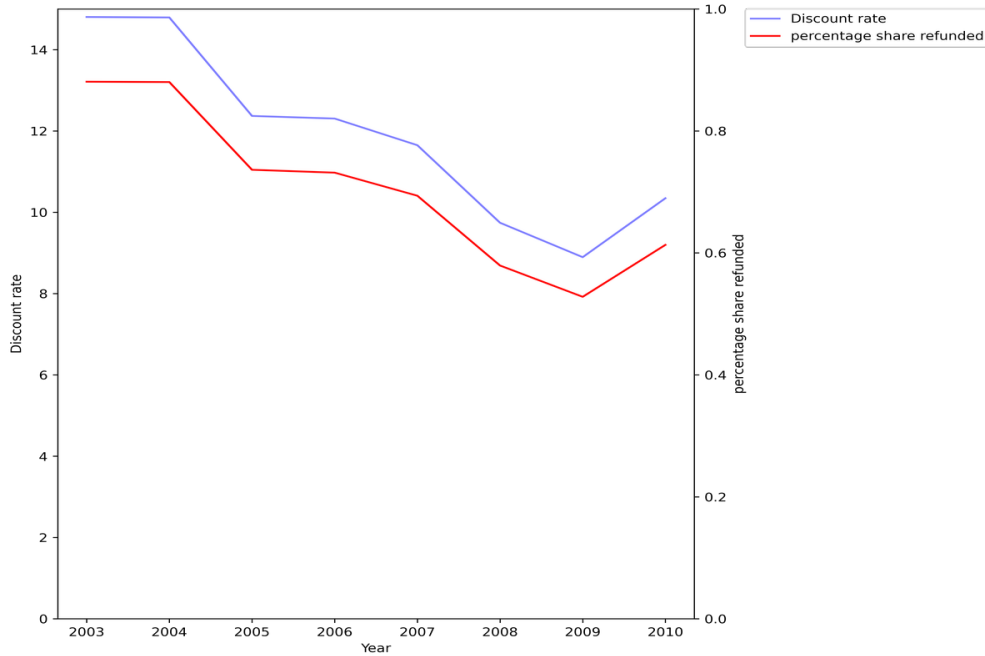


**Source:** General Administration of Customs People's Republic of China for the export data and the World bank for the economic growth rate

To change the structure of its economy, China relies extensively on industrial policies, and one of the most preferred tools by Beijing to manipulate the trade composition is the value-added tax rebate on exports. As explained by Feldstein and Krugman (1990), the VAT rate applied to intermediate goods must be uniform for all commodities purchased on the domestic market or from abroad, meaning that VAT should be impartial and orthogonal to the country's competitiveness. However, China does not adopt such a point of view and decides to cherry-pick products that the government wants to promote or cease producing. For instance, aviation and medical commodities or high-tech sectors are promoted products, while energy-consuming products are meant to drop out of the export market. In practice, a producer is given a base rate of 17 percent, and then the firm needs to browse in circular No 7 (Finance Ministry and the State Administration of Taxation in China 2002) to see the discount rate applied, if applicable. For example, a product with a 17 percent VAT rate and a 13 percent discount rate means 4 percent tax for the exporting company (or 76% refund of the VAT). The amount of VAT payable is based on the quantity exported. The VAT system has undergone many changes since 1994. Initially, the system served as a means to improve the competitiveness of Chinese firms. Since then, the government has continued to use this lever to promote targeted industrial sectors. Between 2002 and 2006, only a small category of products had a total VAT refund. VAT rebates affect all products in a non-uniform way. The trend moved somewhat downwards during the same period, but some products were affected much more than others, as depicted in figure 10. The red line (left axis) shows the discount rate, and the blue line (right-axis) plots the percentage share refunded (discount rate/base rate).

Our objective is to study the effect of the VAT rebate to push product upgrading from 2003 to 2010. To some extent, product upgrading benefits both the economy and the environment for different reasons. Higher-quality products reach wealthier consumers who

**Figure 10: VAT rebate share across time**



**Source:** Circular No 7 from the Ministry and the State Administration of Taxation

are willing to pay a higher price for responsible products (environmentally friendly, better input, etc.), translating into a better margin for the exporter. In addition, cross-country within-firm-level analyses have primarily demonstrated that large firms charge a higher price, especially in distant markets, pay higher wages, and purchase inputs of higher quality to produce more expensive products (Bastos and Silva 2008; Görg et al. 2017). Our analysis is based on the model of Fan et al. (2015) whereby quality decreases with credit constraint. We extend his model by explaining how the VAT tax rebate can alleviate the credit needs faced by constraint firms to finance either the larger upfront cost required in the export market or by investing in innovation. Said differently, the change in VAT rebate relieves firms from a tax burden and, therefore, will promote investment in fixed capital, R&D, and innovation. Hence, this new cash inflow is used to increase the amount of capital equipment put into production, increase R&D expenses, and consequently, product upgrading will follow.

VAT export rebate is exogenous to the exporter, but the product quality may not be,

contaminating our estimation. Hence, to minimize the endogeneity problem, we use the trading system's duality to differentiate the export flow between the "ordinary" traders and the "processing" traders. In China, exporters can opt for one of these two regimes based on their objectives. Ordinary trade is the most common type for exporting firms. Ordinary trade means the firm pays the import and export tax, including the VAT rebate, under the "exempt, credit, and refund" method. "Processing" trade has a different role in international trade. The primary objective is to import raw materials, components, or intermediate input from abroad and assemble and re-export them. Foreign firms recognize the extreme convenience of this type of trade. The Chinese government gives substantial benefits to foreign firms choosing this status, namely duty-free imports and lower corporate taxes. The "no collection and no refund" method disqualifies processing traders from applying for refunds. Officials consider that the firms do not own capital or any other form of purchase. We, therefore, assume that only ordinary traders should react to a change in the VAT rebate and, in response, affect the product upgrading. This estimation strategy is novel since the literature has focused on the effect of trade liberalization, using reduction of import tax, to assess the product price change (Bas and Strauss-Kahn 2015) but ignores the change in quality from an export-tax-industrial policy. We also rely on a new indicator to better capture quality.

Previous studies (Hallak 2006) used unit price to explain international price variations, assuming that higher price is synonymous with better quality. The shortcoming of the unit price is that it captures the difference in production costs across the country, which does not translate inevitably into better quality. Khandelwal (2010) methodology focuses on the vertical components of quality, rather than unit price. It is easily computed by regressing the firm's product demand on the product and country-year fixed effect. The residual, adjusted by sigma,<sup>14</sup> gives the quality. This approach is relatively simple and intuitive: "conditional price, a variety with a higher quantity is assigned higher quality". Another

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<sup>14</sup>Sigma is the country-specific elasticity of substitution provided by Broda and Weinstein (2006)

particularity of this index is that it is highly tractable; we can estimate the quality of a given city–product–destination combination for both types of trade. The trade regime is central to our strategy, and the quality reflects the change in the production mix within a city.

Our results suggest an increase in the product upgrading in response to an increase in the VAT refund. The economic effect is large; an increase in the rebate of 10 percentage points increases the product upgrading by about 26% for the eligible companies and largely depends on the industry and destination country. The trade literature has documented that larger firms have higher productivity, set higher prices, and display better mark-ups (Manova and Zhang 2012). Our results also show that ordinary traders comply with the importing countries' regulations. The use of non-trade barriers to raise the standard from the country of import pushes ordinary traders to increase the quality. We confirm those findings by showing that larger industries export goods of better quality when compared to smaller industries. The model shows a differential of 7 percentage points in the product upgrading following an increase of the rebate for large industries compared with small industries. Finally, we investigate the difference in taste based on the destination country's income. Empirical evidence shows that richer countries consume more high-quality products, which is validated in our estimations. Exporters increase the quality in response to a positive change in the rebate when the destination market has a higher income. The exporters can use a positive change in the rebate to initiate a product upgrade and enter more profitable, but also more demanding, markets. The results align with the model's prediction of Fan et al. (2015), whereby tighter credit constraints force firms to produce lower-quality products. We extend his intuition by providing a counter-balance force to credit constraint and adjusted quality. By increasing the refund granted to ordinary traders, firms use this excess cash flow to invest (in a fixed asset or innovative project), improving the quality.



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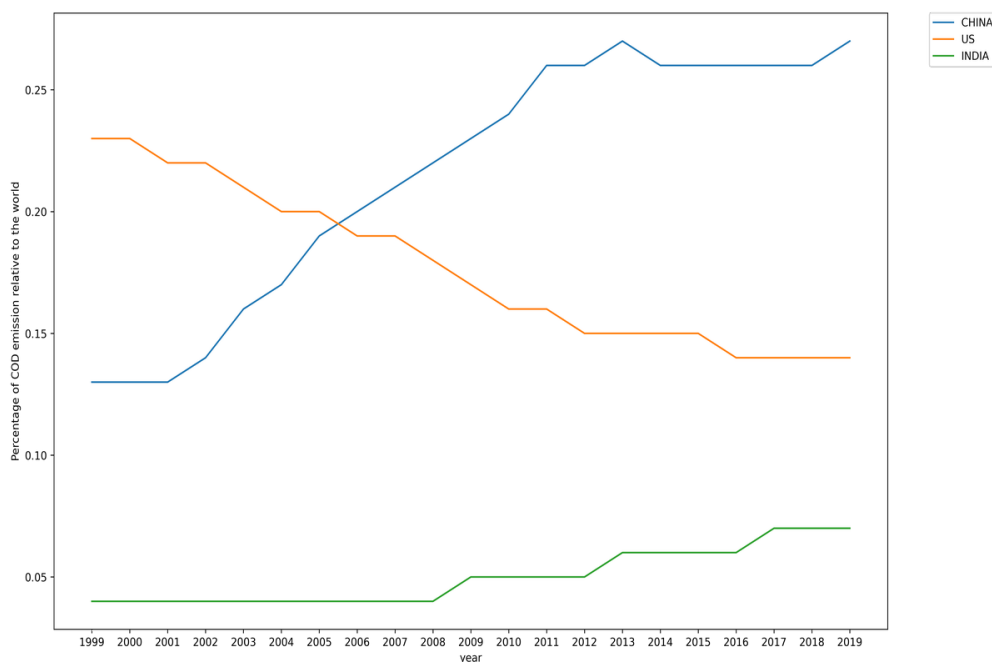
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# Introduction in French

Ces dernières années, l'expansion rapide de l'industrialisation de la Chine est devenue plus qu'alarmante. L'industrialisation de masse, alimentée par des industries à forte intensité en carbone, a poussé la Chine au bord d'une crise environnementale sans précédent. La voie de développement empruntée par la Chine, combinée à un manque d'engagement politique solide envers l'environnement, a mis en péril un écosystème déjà très fragilisé. Avec l'expansion du changement climatique, la rareté de l'eau, la contamination des sols, l'épuisement des forêts et la pollution de l'air ne sont que quelques défis parmi d'autres à relever dans les années à venir.

**Figure 11: Part mondiale des émissions de COD en Chine, aux États-Unis et en Inde**



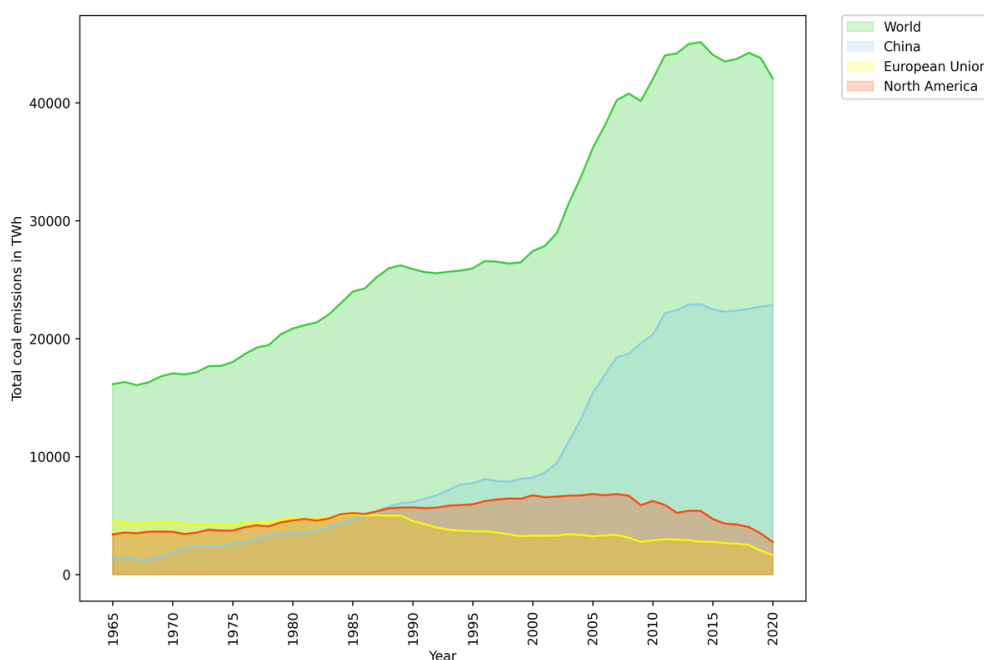
**Source:** <https://ourworldindata.org/co2-emissions>

Les conséquences environnementales perceptibles en Chine ne se limitent pas à ses frontières. Aujourd'hui, la Chine est le plus grand émetteur au monde de demande chimique en oxygène (DCO)<sup>15</sup>, représentant environ 27% des émissions mondiales en 2019, avec une moyenne annuelle de 4% (stabilisée à 1% après 2011) comme indiqué dans la figure 11. L'appétit incessant

<sup>15</sup>La demande chimique en oxygène est définie comme une "mesure de la quantité d'oxygène requise pour oxyder la matière organique et inorganique oxydable contenue dans un échantillon" Hu and Grasso 2005). La DCO est souvent utilisée pour mesurer les polluants de l'eau, des eaux usées et des déchets dangereux.

de la Chine pour le charbon est hors de portée. Les économies développées, telles que l'Union européenne ou les Etats-Unis, ont considérablement réduit leur dépendance au charbon,<sup>16</sup> tandis que la Chine continue d'en consommer (voir figure 12) et d'ouvrir des mines à un rythme déraisonnable.<sup>17</sup> Sur l'année 2020, la Chine a construit 41016 nouvelles centrales à charbon en exploitation (voir figure 13) et il n'y a aucun engagement politique du Parti à mettre fin à l'utilisation des combustibles fossiles au niveau national.

**Figure 12: Émissions totales de charbon en Chine par rapport aux économies développées**



**Source:**

<https://ourworldindata.org/grapher/coal-consumption-by-country-terawatt-hours-twh>

Les défis environnementaux de la Chine ne sont pas nouveaux, et pour comprendre l'origine du problème, nous devons remonter au début de la transition économique. Depuis

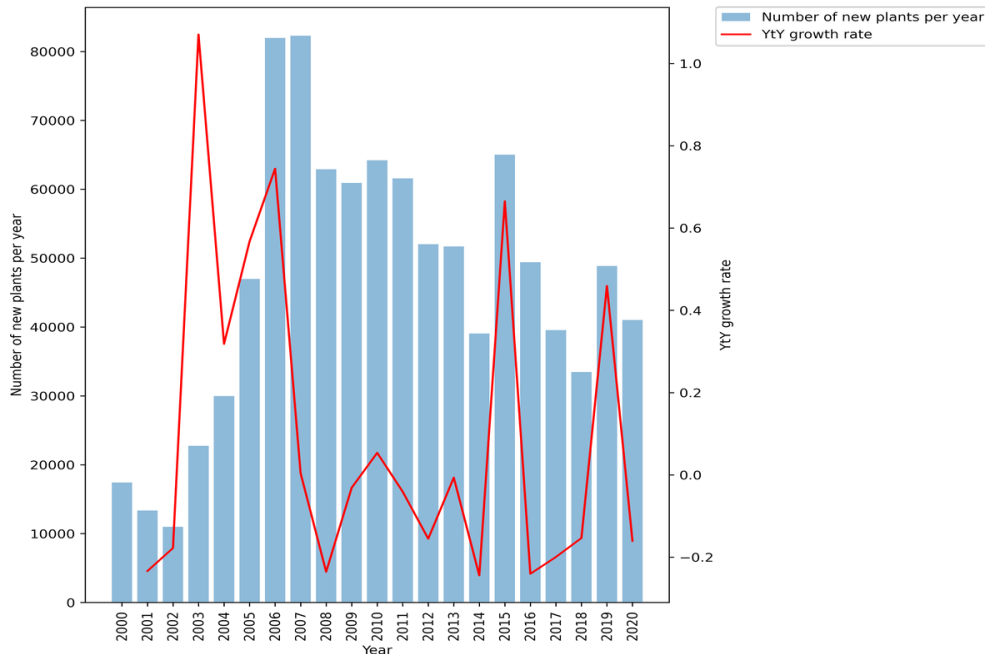
<sup>16</sup>La consommation totale de charbon, mesurée en térawattheure (TWh), de l'Union européenne est d'environ 3% en 2020, 6% pour l'Amérique du Nord et 54% pour la Chine.

<sup>17</sup>Comme indiqué par le Global Energy Monitor, un groupe de recherche, la Chine exploite 66 mines à l'étranger (voir <https://globalenergymonitor.org/projects/global-coal-plant-tracker/tracker/>). Cependant, lors de l'Assemblée générale des Nations Unies de 2021 à New York, Xi Jinping s'est engagé à mettre fin au financement de nouvelles centrales électriques au charbon à l'étranger, qui pourrait impacter jusqu'à 44 projets à divers stades de développement. Source: <https://www.ft.com/content/1c2d592e-2a63-4afd-bda4-69cb406c9d86>



l'ouverture de la Chine en 1978, la croissance économique s'est accélérée à un rythme effarant, entraînant une consommation d'énergie encore plus importante. Pour faire face aux besoins énergétiques, la Chine produit 80% de son électricité à partir de centrales à charbon (IEA: World Energy Investment 2019), cette énergie étant généralement plus polluante que les autres énergies fossiles. Une autre cause des émissions relativement élevées se trouve dans l'utilisation de petites et moyennes centrales à charbon peu efficaces. La dépendance à l'égard du charbon a été exacerbée après son adhésion à l'OMC en 2001, en réponse à l'essor de ses exportations. La figure 14 montre une forte corrélation entre les exportations totales de la Chine et la consommation de charbon, surtout après 2002.

**Figure 13: Nombre total de nouvelles mines de charbon ouvertes en Chine**

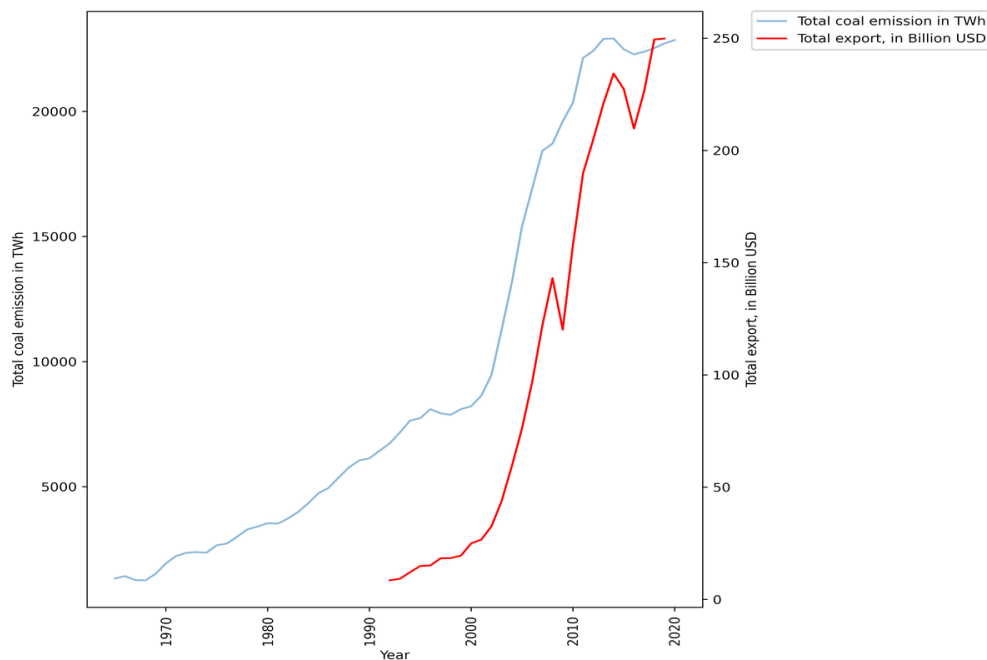


**Source:** <https://endcoal.org/global-coal-plant-tracker/>

La réponse du gouvernement chinois à la question environnementale n'est pas nouvelle car, depuis 1978, un système décentralisé de contrôle et de prévention des polluants a été mis en place. L'efficacité de la réponse apportée est cependant plus discutable. De nombreuses catastrophes environnementales et l'augmentation de la pollution (SO<sub>2</sub>, CO<sub>2</sub> et autres polluants primaires) poussent le gouvernement central à agir. Les dégâts causés par les pluies

acides étaient parmi les plus importants au monde et coûtaient environ 0.7% du PIB au début des années 1990 (The World Bank 2007). En 1998, les dirigeants du parti ont proposé d'établir une liste des villes ayant de mauvaises performances environnementales en matière d'émissions de SO<sub>2</sub> et de pluies acides. De cette façon, la politique des "Two Control Zone" est née et elle est toujours en vigueur aujourd'hui.

**Figure 14: Évolution annuelle du charbon et des exportations en Chine**



**Source:** Source for export: World bank and source for coal is ourworldindata

Le gouvernement chinois ne nie pas le grave problème de pollution et les dirigeants du parti sont bien conscients du lourd héritage des coûts environnementaux. Le vrai défi est de trouver un équilibre entre le développement économique et la protection de l'environnement. L'objectif principal de la Chine est de réduire la pauvreté, ce que seul un taux de croissance élevé peut rendre possible. Au fur et à mesure que la population s'est enrichie, l'augmentation de la sensibilisation à l'environnement et du mécontentement a poussé le gouvernement central à intégrer plus formellement des politiques environnementales, visant à freiner la dégradation de l'environnement. Le premier objectif environnemental a été

adopté au cours du 10e plan quinquennal (2001-2005), stipulant une réduction de 10% des émissions totales de SO<sub>2</sub> en 2005 par rapport aux niveaux de 2000. La fragilité et le manque de coordination/supervision de la loi ont abouti à un désastre total. Non seulement les émissions de SO<sub>2</sub> n'ont pas diminué, mais elles sont montées en flèche de manière inédite. Le problème inhérent à cette loi venait de la divergence des objectifs entre le gouvernement central et les gouvernements locaux. Les gouvernements locaux étaient peu incités à poursuivre des objectifs environnementaux puisqu'il n'y avait pas de récompense à la fin de leur mandat politique. Suivre les politiques de réduction de SO<sub>2</sub> était perçu comme dénué de sens, car la stratégie de développement globale de la Chine restait fermement ancrée dans une perspective de croissance économique. La carrière et les rémunérations dépendaient d'objectifs sociaux tels que l'emploi ou la performance économique, comme le taux de croissance. L'échec de l'un de ces objectifs entraînait des conséquences bien plus graves qu'un échec environnemental.

Reconnaissant cet échec, le gouvernement central a décidé de modifier son approche descendante (top-down) vers une approche montante (bottom-up). Dans le 11e plan quinquennal, l'objectif a été ventilé au niveau de la province, rendu obligatoire et lié à la carrière des gouverneurs. Un nouveau ministère a été créé en 2007 pour remplacer l'Administration Nationale de la Protection de l'Environnement (SEPA), afin d'apporter plus de crédibilité à l'objectif. Fin 2010, la Chine a réussi à stabiliser ses émissions de SO<sub>2</sub>, et quelques années plus tard, le cap était atteint.

En revanche, le niveau de pollution restait hors norme par rapport aux standards de l'OMS. Pour donner un exemple concret, la moyenne mensuelle des PM<sub>2,5</sub> dans les 50 plus grandes villes de Chine n'a jamais été inférieure à 25 (recommandation de l'OMS). En 2014, le Premier ministre Li Keqiang s'est engagé à entrer en guerre contre la pollution. Un an plus tard, la Chine a signé l'accord de Paris, s'engageant à réduire l'intensité carbone du pays de 60 à 65% d'ici 2030, par rapport au niveau de 2005. L'enjeu est de taille car l'appétit énergétique de la Chine est sans équivoque. Il y a peu de signes de réduction de la

consommation de charbon et une réduction substantielle des polluants de l'air ou de l'eau.

Depuis longtemps, la littérature a documenté le rôle des exportations, de la croissance et de la dépendance à l'égard de l'industrie lourde, pour expliquer les émissions de polluants ou les performances environnementales. Cependant, il y a un manque de littérature sur le rôle du système financier sur la performance environnementale.

## **Effet d'une mauvaise allocation des ressources financières sur les émissions de polluants**

Le chapitre premier de la thèse vise à expliquer la relation entre le système financier et les émissions de polluants. La littérature la plus récente démêle l'impact du commerce, de la concurrence et de la réglementation sur les émissions ou la réduction de la pollution, mais seuls quelques articles se concentrent sur les contraintes financières (Andersen 2017; Zhang and Zheng 2019). Dans le premier chapitre, nous démontrons qu'un système financier défaillant pénalise les entreprises privées qui cherchent des financements externes, ce qui conduit à plus d'émissions polluantes par un surinvestissement en actifs corporels. Le rôle des banques dans une économie est vital, en particulier pour les entreprises, car elles se financent, généralement avec des prêts pour financer leurs activités commerciales. Dans un marché du crédit qui fonctionne bien, les banques créent des liquidités en prêtant de l'épargne aux entreprises après avoir évalué le risque de défaut.

Par ailleurs, le moyen le plus efficace pour réduire les dégâts environnementaux causés par les activités économiques, consiste à y remédier en introduisant des technologies et des pratiques respectueuses de l'environnement, en supposant qu'elles puissent être financées.

Les banques exigent également de l'emprunteur des garanties. Le terme collatéral fait référence à un actif qu'un prêteur accepte en garantie d'un prêt. Dans la plupart des cas, le collatéral prend la forme d'un actif physique, qui peut être facilement converti en valeur monétaire en raison de sa grande liquidité. Le rôle principal du collatéral est de protéger le prêteur en cas de défaut; c'est-à-dire que l'emprunteur peut saisir le collatéral et le revendre

pour minimiser sa perte. Le collatéral doit être proportionnel à la taille du prêt et garantir que l'emprunteur continuera à rembourser sa dette jusqu'à la fin. Par ailleurs, les entreprises peuvent utiliser le marché des actions (ou marché boursier) pour acheter des titres de créances tels que des obligations pour se financer.

Les obligations sont l'un des moyens les plus typiques des économies développées pour réaliser une augmentation de capital. Les entreprises obtiennent de l'argent de la part des investisseurs, puis elles payent un taux d'intérêt jusqu'à maturité et enfin elles remboursent le principal. Selon le théorème de Modigliani-Miller (Modigliani and Miller 1958), le système financier alloue efficacement les ressources quel que soit le choix de financement - qu'il s'agisse d'un financement interne tel que de la trésorerie, ou en empruntant de l'argent à une institution financière (banques), ou en levant des fonds grâce à de nouvelles actions.

La littérature a largement exploré le modèle Modigliani-Miller pour déterminer si une entreprise ou une industrie est financièrement contrainte. En 1998, Rajan and Zingales (1998) ont proposé une méthodologie pour surmonter les critiques des études empiriques précédentes souffrant d'endogénéité. Les auteurs ont défini la dépendance financière d'une industrie comme la part des dépenses en capital non financées par les flux de trésorerie provenant de l'appareil productif. Les auteurs utilisent les données américaines des sociétés cotées sur la période 1980-1990 pour tous les secteurs. L'idée derrière l'indicateur de financement externe est que si une industrie est financièrement plus vulnérable, elle est plus susceptible de faire face à des contraintes de financement. Une autre façon de lire cette variable est de penser que la vulnérabilité financière reflète la différence dans les caractéristiques technologiques de chaque industrie. En un mot, lorsque la dépendance externe est importante, l'industrie est financièrement vulnérable et dépend du financement externe.

En Chine, un consensus émerge sur le fait que le système financier est déficient et que la contrainte de crédit prévaut, dans une industrie dominée par le secteur privé. Les banques d'Etat dominant le marché en fournissant plus de 60% des prêts (Ping 2003), mais rationnent le montant des flux vers les entreprises privées. Pour poursuivre leur développement et

alimenter la croissance chinoise, les entreprises privées ont dû utiliser leur trésorerie pour investir dans la recherche et le développement et d'autres activités améliorant la productivité (Guariglia et al. 2011). L'utilisation de la trésorerie a donné aux entreprises privées plus de liberté dans les projets à financer. En effet, il existe une littérature expliquant la limite du marché du crédit. Les entreprises qui sont limitées dans leur financement interne n'ont d'autre choix que de s'appuyer sur un prêteur externe et, dans le cas de la Chine, les banques. Le marché des actions en Chine au cours de notre analyse (avant 2010) était inexistant (la capitalisation boursière de la Chine en 2000 était inférieure à 1,000 milliard contre 13,000 milliard de dollar en 2021.<sup>18</sup>). Il convient de noter que le marché des actions est censé réduire la sélection adverse et l'aléa moral, réduisant ainsi le coût du capital externe de l'entreprise. En revanche, les banques ne sont pas aptes à supporter le risque de financer l'innovation par la recherche et le développement. Contrairement au marché des actions, les banques sont relativement averses au risque, ce qui les empêche de financer l'innovation.

Selon Stiglitz (1985), les industries ayant une dépendance financière externe importante ont tendance à sous-investir dans des projets innovants. Une des raisons principales vient de l'exigence d'un collatéral. Le collatéral doit avoir une valeur monétaire finie que la banque peut évaluer. Cependant, pour Berger and Udell (1990), un projet de recherche et développement ne constitue pas une garantie à mettre en gage, car la propriété intellectuelle ou le modèle est complexe à revendre pour une banque, et la valeur intrinsèque revêt une plus grande incertitude que celle des actifs corporels. Pour Morck and Nakamura (1999), le marché du crédit est fortement orienté vers des investissements conservateurs, traditionnellement des actifs tangibles, ce qui conduit les entreprises à repousser ou à renoncer à des projets innovants. Par conséquent, le marché du crédit décourage l'innovation et le financement des actifs incorporels.

La figure 15 confirme l'hypothèse selon laquelle les entreprises appartenant à des secteurs financièrement contraints ont tendance à avoir une plus grande part d'actifs corporels dans

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<sup>18</sup>Source: <https://www.ceicdata.com/en/indicator/china/market-capitalization>

leur bilan. <sup>19</sup>

Nous avons utilisé des données de firmes provenant du jeu de données "ASIF" pour construire la part des actifs corporels par rapport aux actifs totaux de 2000 à 2007. Nous avons divisé les industries selon qu'elles dépendent financièrement ou non à des financement externe. Pour définir une industrie contrainte financièrement, nous empruntons les valeurs de Fan et al. (2015), qui répliquent la méthodologie de Rajan and Zingales (1998) mais en utilisant les données chinoises. La dépendance financière externe est disponible pour 29 industries. Nous avons pris la valeur médiane (- 0,47) pour répartir les industries de manière égale entre les contraintes et les non-contraintes. La ligne bleue représente la part des actifs corporels pour les secteurs contraints et la ligne rouge pour les non contraints. Il est flagrant que les industries qui dépendent de financements externes ont une part d'actifs tangibles plus important que leurs homologues non contraints.

La littérature est sans équivoque sur le biais en faveur des actifs corporels dans les industries qui dépendent du financement externe. Cependant, il existe peu de preuves de l'impact des actifs corporels sur les émissions de polluants, à l'exception de Andersen (2017) qui propose un modèle où la contrainte de crédit fausse l'allocation d'actifs optimale (corporel *versus* incorporel). Le biais en faveur des actifs corporels (la faveur accordée au actifs corporels) découle généralement du fait que les banques sollicitent un collatéral en gage du crédit, et que les actifs incorporels ne peuvent constituer un collatéral utile, n'ayant pas de valeur "calculable". Andersen démontre que les crédits garantis par des actifs corporels sont positivement corrélés aux émissions de pollution, établissant un lien entre ce type de crédit et l'augmentation des émissions. Plus récemment, Zhang and Zheng (2019) a exploré les effets des contraintes financières sur la réduction de la pollution au niveau des entreprises en Chine.

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<sup>19</sup>Un actif corporel est un actif ayant une valeur monétaire finie et généralement une forme physique. Les actifs corporels peuvent toujours être négociés pour une certaine valeur monétaire, la liquidité des différents marchés pouvant varier. Les actifs corporels sont à l'opposé des actifs incorporels avec une valeur théorique plutôt qu'une valeur d'échange transactionnelle. Les immobilisations corporelles sont le type d'actifs le plus élémentaire du bilan. Ils sont, le plus souvent, la principale forme d'actifs dans la plupart des industries. Ils sont aussi généralement les plus faciles à comprendre et à valoriser

**Figure 15: Part des actifs corporels dans les industries contraintes et non contraintes**



**Source:** ASIF firm-level data and authors' own computation

Les auteurs montrent que la contrainte financière fait obstacle à la réduction de la pollution de l'air. En utilisant les données de la base de données statistiques environnementales chinoise,<sup>20</sup> nous montrons en figure 16 l'évolution du SO<sub>2</sub> et des actifs corporels par rapport aux actifs totaux de 2000 à 2007. Les deux lignes évoluent dans le même sens au fil du temps, montrant une relation potentielle entre l'effet des actifs corporels sur les émissions de SO<sub>2</sub>.

## **Effet de la contrainte budgétaire souple et de la politique environnementale sur les émissions polluantes**

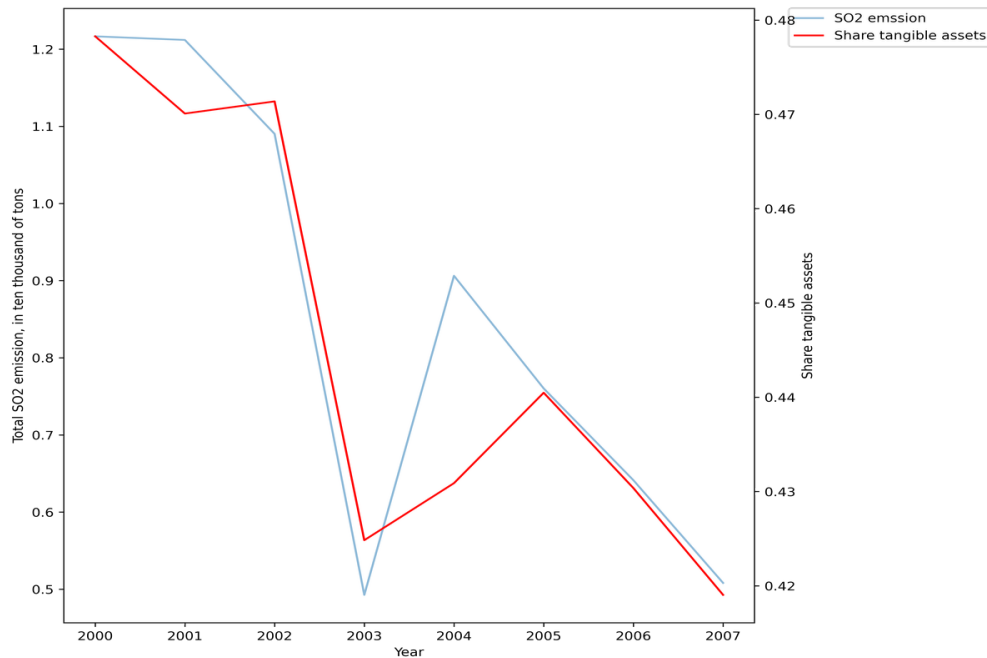
Le problème de financement n'affecte pas toutes les entreprises en Chine, les entreprises privées étant habituellement les plus touchées. Le gouvernement chinois a toujours privilégié

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<sup>20</sup>Depuis 1980, le MEP a mis en place un système de statistiques environnementales pour collecter des données sur les polluants et les déchets environnementaux. Cette base de données couvre toutes les provinces, avec des usines considérées comme des entreprises plus importantes qui sont sous la surveillance directe du MEP.



Figure 16: Émission totale de SO2 par rapport à la part des actifs corporels



**Source:** ASIF firm level data and SO2 emission data comes from the Ministry of Environmental Protection

les entreprises publiques, lorsqu'il s'agit d'industries critiques (ressources naturelles, télécoms, banque, santé, etc.), ayant des objectifs sociaux et, dans une certaine mesure, les renflouant en cas de besoin. Cette dernière fait référence à la contrainte budgétaire molle (*Soft Budget Constraint*), un concept développé par Kornai au début des années 90 (Kornai 1993). La contrainte budgétaire molle implique que lorsque le contrat de crédit entre deux parties n'est pas exécuté, le bailleur de fonds assiste l'entreprise en grande difficulté financière, sans réel espoir de remboursement de la dette. De nombreux éléments de preuves démontrent l'existence d'une contrainte budgétaire molle pour les entreprises publiques, alors que les entreprises privées font face aux contraintes de crédit. La contrainte budgétaire molle est toujours applicable en Chine. Les agences de notation internationales et les gestionnaires de fonds critiquent depuis longtemps la note de crédit des entreprises, qui est artificiellement élevée, les faibles taux de défaut en Chine, soulignant un manque de transparence, et l'hypothèse selon laquelle le gouvernement renflouera les entreprises en difficulté. <sup>21</sup>

<sup>21</sup>Financial Times, Corporate Bond Downgrades by China Rating Agencies Triple, May 17th, 2021.

Le concept de contrainte budgétaire molle voit une application directe à l'objectif de croissance durable: les entreprises publiques ou privées ne sont pas motivées pour atteindre l'objectif de réduction de la pollution car elles ont conscience qu'elles peuvent obtenir des crédits de manière abondante. La deuxième partie du premier chapitre traite de l'effet inverse de la politique environnementale édictée par le gouvernement central et du manque d'applicabilité au niveau local, en partie dû au renflouement des entreprises publiques. Plus précisément, quelles circonstances extérieures, au-delà de la contrainte budgétaire molle, importent pour réaliser des objectifs environnementaux en Chine? Le système de rotation des cadres, qui transfère les fonctionnaires à de nouveaux postes tous les trois à quatre ans, peut être la raison pour laquelle les gains à court terme, y compris s'agissant de l'extraction de rentes des entreprises polluantes locales, seraient favorisés par rapport au gains à long termes, dont les cadres ne pourraient pas bénéficier. Des études ont montré que les villes dont les maires sont plus instruits atteignent le point de retournement de la courbe environnementale de Kuznets à des niveaux de revenus par habitants inférieurs (Zheng et al. 2014).

Finalement, occupant des postes plus élevés que les fonctionnaires locaux, les cadres supérieurs des entreprises publiques se perçoivent comme étant au-dessus de la loi locale. En conséquence, certaines villes sont peuplées d'entreprises publiques qui violent les réglementations environnementales tout en générant des emplois essentiels aux évaluations des performances des maires locaux. Le chapitre reviendra sur la question du comportement des villes en matière de réglementation environnementale.

Le régulateur chinois a décidé de prendre la question environnementale au sérieux après que le pic de dioxyde de soufre (SO<sub>2</sub>) a frappé le pays en 1995. En moins de trois ans, les responsables de Pékin ont proposé et ratifié une loi réglementant les émissions de SO<sub>2</sub>. En 1998, le gouvernement central a mis en œuvre la politique de zone de contrôle des pluies acides et de zone de contrôle de la pollution par le dioxyde de soufre, abrégée en politique des "Two Control Zone" (TCZ), pour limiter les émissions de polluants. Alors que la réglementation des émissions de SO<sub>2</sub> a été initialement conçue pour être mise en œuvre au niveau national,

le Conseil d'Etat a ensuite choisi 175 villes TCZ avec des antécédents environnementaux déplorable pour engager davantage d'efforts. Trois critères de sélection ont été retenus en fonction des performances environnementales préréglementaires. Une ville était ciblée par la politique, si la concentration annuelle moyenne de SO<sub>2</sub> ambiant dépassait la norme nationale de classe 2 (0,06 mg/m<sup>3</sup>), ou si la concentration quotidienne moyenne de SO<sub>2</sub> ambiant dépassait la norme nationale de classe 3 (0,25 mg/m<sup>3</sup>). Au total, ce sont 175 villes qui ont été ciblées par la politique.

Les 175 villes étaient concentrées principalement dans deux régions: le nord de la Chine, en raison de sa forte dépendance au charbon pour alimenter les systèmes de chauffage, et le sud de la Chine, où les centres urbains industrialisés émettaient une pollution atmosphérique importante et étaient à l'origine de fortes pluies acides. Les villes TCZ couvraient 1,09 million de kilomètres carrés dans 27 provinces, représentant 11,4% de l'ensemble du territoire chinois. Au niveau national, les objectifs étaient les suivants: les émissions de SO<sub>2</sub> devaient diminuer successivement en 2000 et 2010, et un rôle particulier était attribué aux villes TCZ, qui étaient chargées d'atteindre la norme nationale de classe 2 de 0,06 mg/m<sup>3</sup>. Le quota d'émissions de SO<sub>2</sub> fixé par le gouvernement central en 2000 ne devait pas dépasser 24,6 millions de tonnes - contre 23,7 millions de tonnes en 1997 - et les émissions en 2010 devaient diminuer encore plus qu'en 2000. En 2001, les décideurs ont renforcé la cohérence nationale de la politique environnementale, appelée politique de contrôle dans le 10e FYP (2001-2005). L'entrée de la Chine dans l'Organisation mondiale du commerce en 2001 a lancé un processus d'industrialisation massive, de croissance économique et de réduction de la pauvreté, en contradiction avec la réalisation de l'objectif d'un contrôle plus strict de la pollution.

Les conséquences du manque de coordination et de l'accent mis sur la croissance économique par les gouvernements locaux ont conduit à un pic historique d'émissions de SO<sub>2</sub> en 2005, celles-ci ayant été multipliées par 45% de 2002 à 2005. Les mauvais résultats de la politique environnementale ont été attribués à la conception de la politique elle-même. Son principal

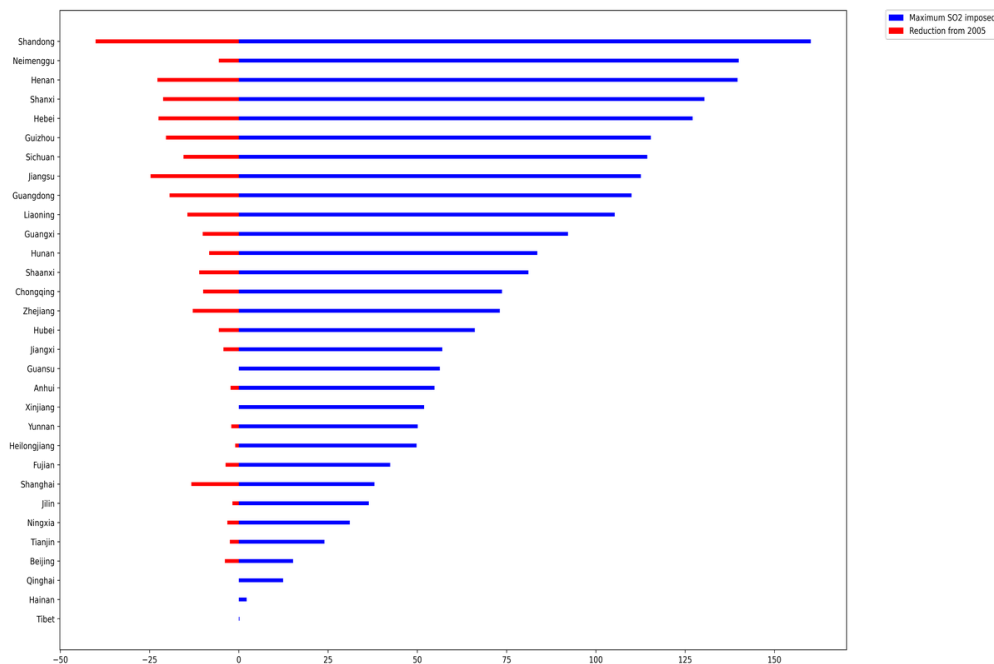
défaut était que les objectifs fixés au niveau national n'étaient pas assez contraignants au niveau local. En conséquence, le gouvernement central a fortement mis l'accent sur la croissance économique, ce qui n'a pas incité les municipalités locales à poursuivre simultanément la croissance économique et la lutte contre la pollution. Ces objectifs se sont souvent révélés contradictoires et ne pouvaient être atteints simultanément (Barbier and Burgess 2019; Brajer et al. 2011; Lee and Oh 2015).

En 2006, le gouvernement central a reconsidéré sa stratégie, passant d'une approche descendante à une approche ascendante. Faisant écho à la littérature académique, qui a fourni des recherches approfondies sur les motivations des bureaucrates à mettre en œuvre une politique particulière. Les deux principales différences introduites dans le 11e plan quinquennal (2006-2010), par rapport au plan quinquennal précédent (2001-2005), étaient la formulation d'une politique claire et de directives de réduction à destination des provinces chinoises, et la mise en place d'un système d'évaluation par objectifs environnementaux, pour la promotion et l'évolution de la carrière des fonctionnaires locaux. Le système d'évaluation par objectifs vise à favoriser les efforts en vue d'atteindre les objectifs jugés prioritaires par l'Etat. Le gouvernement central a fourni un outil pour mesurer le succès de l'administration locale, en la rendant responsable.

La menace imposée par Pékin a contraint les maires et les secrétaires du parti à adhérer à la politique nationale. Zheng et al. (2014) a souligné que les nouvelles incitations sont en grande partie responsables du succès de la nouvelle réglementation. En 2006, le gouvernement chinois a décidé de décomposer l'objectif national de SO<sub>2</sub> au niveau provincial. La nouvelle politique fixe des objectifs audacieux de réduction de SO<sub>2</sub> basés sur le niveau de SO<sub>2</sub> de 2005. Les provinces les plus émettrices de pollution en 2005 se sont vues attribuer des réductions plus importante en 2010. La figure 17 montre la quantité maximale de SO<sub>2</sub> tolérée en 2010 pour chaque province de la Chine (barre bleue) et la réduction obtenue sur la base du niveau de 2005 (barre rouge). Par exemple, en 2005, Shandong était le plus grand pollueur, avec un total de 200300 tonnes de SO<sub>2</sub> émis. En 2010, le montant maximum du

Shandong ne pouvait pas dépasser 160,2, soit une réduction de 40 000 tonnes.

**Figure 17: Objectif de réduction des émissions de SO2**



**Source:** MEP Dataset

Répondre aux questions sur l'absence d'un système financier efficace sur l'environnement nécessite d'obtenir des données sur les émissions de pollution. Les données environnementales chinoises sont extraordinairement détaillées et couvrent la plupart des industries à travers le pays. Depuis 1980, le ministère de la protection de l'environnement (ci-après MEP) a mis en place un système de collecte de données sur la protection de l'environnement et les déchets. Les données sont collectées auprès d'usines considérées comme des entreprises importantes et sous le contrôle du MEP. Les entreprises sont tenues de déclarer elles-mêmes leurs émissions de polluants chaque année, et pour s'assurer que les entreprises déclarent les données avec diligence, le MEP effectue une surveillance et des inspections surprises. En cas de rapports médiocres ou incorrects, l'entreprise fait face à de graves conséquences.

Il convient de noter que ces données sur la pollution sont collectées au niveau de l'usine de fabrication. En résumé, le jeu de données fournit des informations sur les principaux

polluants en Chine, à savoir le dioxyde de soufre, les eaux usées, la suie et le CO<sub>2</sub>. Dans les chapitres 1 et 2 de cette thèse, nous analysons ce jeu de données au niveau ville-secteur de 1998 à 2007. L'une des principales raisons de l'utilisation des données au niveau ville-secteur est que le partage des données au niveau de l'entreprise n'est pas très aisé à obtenir, s'agissant de données particulièrement sensibles.

Le système financier en Chine est marqué par des difficultés, notamment les problèmes rencontrés par les entreprises pour l'obtention de crédits auprès des banques (c'est-à-dire les contraintes de crédit) et le favoritisme envers les entreprises publiques en matière de financement. Les entreprises privées parviennent à faire face à la forte demande intérieure et internationale en utilisant leur financement interne<sup>22</sup> comme documenté par Guariglia et al. 2011; Chen and Guariglia 2013 ou Héricourt and Poncet (2009). Peu d'éléments permettent cependant d'évaluer l'impact du type de financement sur l'émission de pollution. Andersen (2017) fournit un cadre théorique pour expliquer la relation entre la contrainte de crédit et les émissions polluantes. Nous prolongeons son analyse en explorant la variation de la finance interne pour expliquer l'évolution des émissions de SO<sub>2</sub> en Chine de 2001 à 2007.

D'une part, nous nous appuyons sur le jeu de données environnementales le plus complet de Chine pour construire les émissions de SO<sub>2</sub> ville-industrie-année. D'autre part, nous construisons la finance interne (flux de trésorerie et liquidités) à partir des enquêtes manufacturières en Chine, les données ASIF étant collectées par le Bureau national des statistiques de Chine (NBS). Nos résultats confirment l'hypothèse de Andersen (2017) selon laquelle les actifs corporels sont positivement corrélés aux émissions polluantes. Les entreprises contraintes ont peu d'options pour emprunter de l'argent via les réseaux bancaires car ces derniers exigent des garanties pour couvrir le crédit, ce qui les empêche d'investir dans la recherche et le développement. Ensuite, nous démontrons que la disponibilité de liquidités réduit les émissions de SO<sub>2</sub> avec un effet plus fort sur les entreprises privées et domestiques. Une anal-

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<sup>22</sup>Selon la théorie de la structure du capital, le financement interne est la procédure par laquelle une entreprise utilise ses bénéfices ou ses actifs comme source de capital pour financer un nouveau projet ou investissement. L'opposé du financement interne est le financement externe, qui concerne les prêts, les obligations ou les émissions de capitaux propres.

yse plus approfondie est menée dans la deuxième partie du chapitre pour expliquer l'absence de corrélation entre les entreprises publiques et les émissions de pollution.

La présence d'une grande part des entreprises publiques rend difficile la réduction de la pollution et la réalisation des objectifs environnementaux fixés par le gouvernement central. Notre calcul montre que la réduction des émissions de SO<sub>2</sub> a atteint environ 5% des émissions moyennes des secteurs pollués après 2006, dans les villes non dominées par des entreprises publiques. Nous interprétons les résultats comme preuves de la persistance des contraintes budgétaires molles des entreprises publiques chinoises. De plus, nous étudions quatre mécanismes sous lesquels la contrainte budgétaire molle opère.

Tout d'abord, nous essayons de déterminer la non-conformité réglementaire sous-jacente: le chevauchement (ou non) de villes "Two Control Zone" (Special Policy Zone, côtière) où les politiques environnementales (de croissance) sont prioritaires. Les résultats suggèrent que les entreprises des villes TCZ réagissent plus fortement à la réglementation environnementale, et que la TCZ et le plan quinquennal sont complémentaires, sous réserve d'avoir une plus grande part d'entreprises privées.

Deuxièmement, nous nous demandons si la concentration industrielle conduit à des comportements différents des entreprises. Les grandes entreprises sont dans une position de négociation plus forte, elles peuvent poursuivre leurs objectifs et influencer les autorités locales concernant l'application de la réglementation environnementale. Troisièmement, nous calculons la courbe de Kuznets<sup>23</sup> pour déterminer le niveau de revenu par habitant pour lequel la relation entre la pollution et la croissance économique devient négative. L'absence de réaction à la réglementation est spécifique aux villes dominées par les entreprises publiques et peut être interprétée comme symptomatique de la contrainte budgétaire molle.

Nous étudions l'adoption de technologies plus propres par les entreprises polluantes in-

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<sup>23</sup>La courbe environnementale de Kuznets (EKC) suppose qu'il existe une relation (non linéaire) entre divers polluants et le revenu par habitant. Dans les premiers stades de la croissance économique, les émissions de pollution augmentent, et au-delà d'un seuil de revenu par habitant, elles diminuent. Le seuil est différent pour chaque type de polluant. La tendance ressemble à une forme en U inversé indiquant que la croissance économique entraîne une amélioration de l'environnement à un niveau de revenu élevé.

duites par la réglementation, ce qui permet d'améliorer la productivité et réduire les émissions de SO<sub>2</sub>. Il y a deux effets opposés possibles entre la lutte contre la pollution et l'objectif de productivité. Premièrement, un impact positif est probable si l'innovation vise à produire à moindre coût, permettant aux entreprises d'employer moins d'intrants et moins d'énergie sale par unité de production. En imposant une limite stricte et inférieure aux émissions de SO<sub>2</sub>, la nouvelle réglementation oblige les entreprises à se moderniser ou à quitter le marché. Deuxièmement, selon la théorie des coûts de conformité, un effet négatif n'est pas exclu. Si le coût de la réglementation environnementale freine une amélioration de la productivité, cela se traduit par une baisse de la performance industrielle. Les coûts de protection de l'environnement des entreprises les obligent à contourner les investissements dans l'innovation et l'amélioration de la productivité. Cependant, ces mécanismes peuvent ne fonctionner que pour les entreprises privées. Une abondante littérature montre que les entreprises publiques chinoises font état de performances économiques plus faibles et d'une productivité totale des facteurs plus faible. Dans l'ensemble, les résultats suggèrent que l'amélioration technologique induite par les politiques ne vaut que pour les entreprises publiques situées dans les villes TCZ, les villes plus riches et les villes moins importantes avec des niveaux de concentration industrielle plus faibles.

Enfin, trois mécanismes sont à l'origine de ces résultats significatifs. Premièrement, la disponibilité des financements internes réduit le biais en faveur des actifs corporels. Une littérature naissante analyse dans quelle mesure la disponibilité des ressources internes de financement affecte les investissements des entreprises dans les immobilisations, les stocks ou la R&D (Chen and Guariglia 2013; Fazzari et al. 2000; Rajan and Zingales 1998). Selon cette littérature, les entreprises disposant de plus de financements internes sont moins susceptibles d'investir dans des actifs corporels et plus susceptibles d'utiliser leur trésorerie pour financer des innovations technologiques et de la R&D. Du côté de l'offre, les banques sont réticentes à financer les actifs incorporels car ces derniers ne sont pas considérés comme des garanties suffisantes (Brown and Petersen 2009). Les résultats indiquent que la disponibilité



du financement interne fausse l'allocation des actifs au sein des entreprises. Nous trouvons simultanément une association positive entre le financement interne et les dépenses de R&D et une relation négative avec le financement externe (c'est-à-dire l'offre de crédit). De même, la tangibilité des actifs et l'estimation des finances internes manifestent une association négative sans équivoque.

Deuxièmement, la productivité totale des facteurs réduit considérablement les émissions de SO<sub>2</sub>, ce qui est accru lorsque les entreprises ont davantage de financement interne. La littérature a documenté la diminution des émissions polluantes induite par la productivité totale des facteurs, ce qui signifie que les entreprises plus productives sont plus économes en ressources (Brown and Petersen 2009; Fazzari et al. 1988; Li et al. 2018). Dans l'ensemble, nos résultats suggèrent que les entreprises générant suffisamment de flux de trésorerie parviennent à améliorer leur productivité grâce à différents investissements innovants et à l'adoption de technologies. Il en résulte une diminution induite par la productivité totale des facteurs de l'émission de SO<sub>2</sub>.

Enfin, la disponibilité de financements internes contribue à une diminution des émissions de polluants grâce à l'achat d'équipements de lutte contre la pollution. L'utilisation des données du MEP (Wang and Chen 1999) rapporte que les sources d'investissement dans la réduction sont progressivement passées des subventions au profit de l'entreprise. Dans la mesure où l'accès au financement externe est limité pour les entreprises privées et que les subventions se tarissent, nous examinons si le financement interne peut rendre abordable l'acquisition d'équipements de lutte contre la pollution. Nos résultats indiquent que les entreprises mieux dotées en financement interne sont plus susceptibles d'acheter des équipements de réduction de la pollution. Conformément aux résultats de Fan et al. 2021, les grandes entreprises respectant la politique environnementale bénéficient de taux d'intérêt préférentiels sur les prêts, tandis que les petites entreprises n'ont d'autre choix que de réduire la taille du produit lorsqu'elles ne peuvent pas se conformer à la réglementation. Nos résultats vont dans le sens de ce constat. Nous constatons que les petites entreprises sont plus sus-

ceptibles d'investir dans des équipements de réduction de la pollution par le biais de leurs flux de trésorerie, contrairement aux grandes entreprises qui sont moins contraintes.

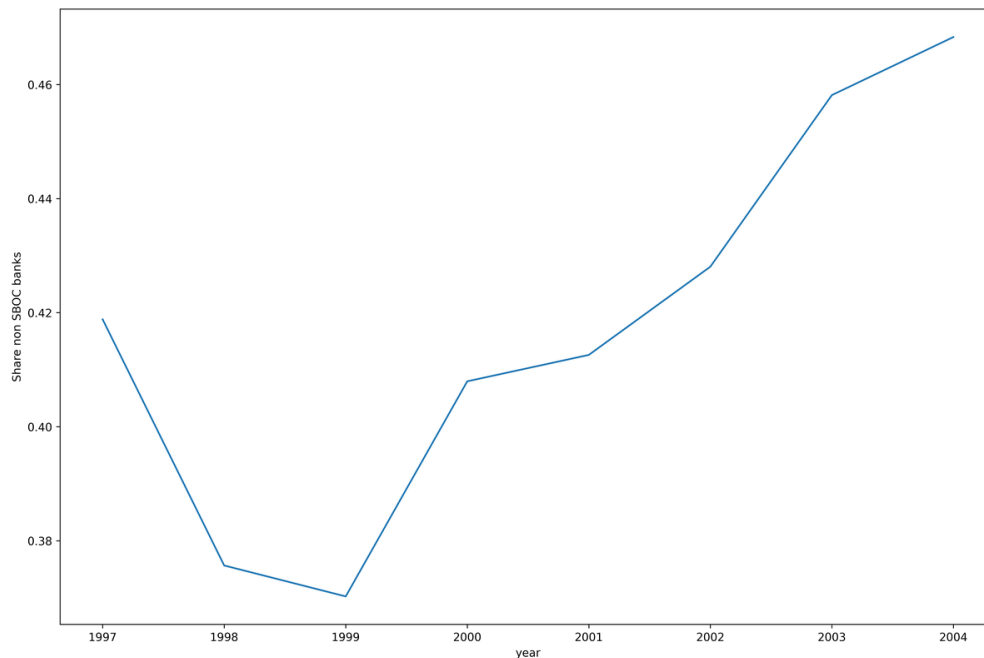
## **Effet du développement financier sur les émissions polluantes**

Dans les deux premiers chapitres de la thèse, nous avons démontré qu'une mauvaise allocation des ressources financières est préjudiciable à l'environnement. En plus de cela, nous avons documenté les mécanismes sous-jacents: distorsion des actifs, contrainte de crédit et contrainte budgétaire molle, entre autres. Dans le troisième chapitre de la thèse, nous adoptons une approche différente pour élaborer des solutions potentielles pour réconcilier la finance et la performance environnementale. Plus précisément, nous évaluons si l'amélioration de l'efficacité du secteur bancaire contribue à réduire les émissions de polluants.

Nous avons vu précédemment que tous les secteurs ne peuvent pas utiliser le financement interne (principalement de la trésorerie) pour investir dans de meilleures ressources, afin d'améliorer la productivité ou d'acheter des systèmes de lutte contre la pollution. Ces secteurs n'ont guère d'autre choix que de lever des fonds par le biais d'un prêt. Dans un contexte comme celui de la Chine, où le secteur bancaire rationne l'offre de crédit, la déréglementation est le seul moyen d'augmenter les flux d'argent vers le secteur privé. La Chine a commencé à ouvrir le secteur bancaire en 1994 avec une impulsion plus forte du gouvernement après 2000. Les réformes bancaires initiées en 1994 visaient à séparer les banques politiques (c'est-à-dire les banques publiques) des banques commerciales. Les quatre principales banques chinoises centrées sur l'Etat (à savoir Industrial and Commercial Bank of China, China Construction Bank Corporation, Agricultural Bank of China et Bank of China) ont émis environ 75% de l'offre totale de crédit, principalement destinée à des entreprises d'état. Etant donné que les principaux bénéficiaires des prêts sont des entreprises d'Etat, qui bénéficient d'une contrainte budgétaire molle, les quatre principales banques ont une forte proportion de prêts non rentables (Ferri and Liu 2009) par rapport aux banques de capital-investissement et aux banques municipales.

Reconnaissant l'incapacité apparente des quatre banques commerciales d'Etat (SBOC) à allouer efficacement les capitaux, le gouvernement chinois a mis en œuvre une restructuration substantielle du secteur bancaire. Cela a commencé en 1994, lorsque le gouvernement a autorisé davantage d'acteurs, principalement avec des banques commerciales municipales détenues par le gouvernement local, des entreprises locales et des actionnaires privés, et en 1996 avec l'apparition de banques étrangères. La pénétration du marché de ces banques a été progressive, comme le montre la figure 18. La part de marché des non-SOBC était à son plus bas en 1999 et n'a cessé de croître depuis.

**Figure 18: Part de l'offre de prêts non SBOC sur le total des prêts**



**Source:** Almanac of China's Finance and Banking

Les vagues successives d'introduction de nouveaux types d'institutions financières ont indéniablement accru la concurrence et stimulé l'efficacité, en particulier dans l'allocation du crédit. Sans surprise, le taux de prêt non performant a diminué vers la fin de 2002 (en réponse à la diminution de la part de marché des SOBC). La libéralisation et la réforme du système bancaire ont transformé les coopératives de crédits urbaines en banques commerciales, elles

ont permis les banques étrangères, limité le système de gestion centré sur l'Etat, etc., et elles ont conduit à une amélioration du paysage financier en Chine (meilleure rentabilité et moins de risques).

L'ouverture bancaire s'est avérée efficace sur la croissance économique, la productivité et les exportations et elle a amélioré l'allocation des ressources entre les industries. Dans le chapitre 2, nous insistons sur les conséquences des réformes du système financier sur la performance environnementale. Des recherches récentes dans les économies développées ont mis en évidence le lien entre le développement financier et l'environnement. Au moins trois canaux pourraient être en jeu, pour comprendre comment une allocation de ressources financières, qui fonctionne bien, affecte la performance environnementale d'une entreprise.

Premièrement, une offre de crédits plus importante, combinée à une meilleure allocation des crédits, peut réduire la pollution en augmentant les investissements dans la lutte contre la pollution (Goetz 2019). En effet, un financement à long terme moins cher pousse l'entreprise à investir dans des systèmes de lutte contre la pollution à forte intensité en capital. Deuxièmement, la disponibilité du crédit permet d'investir dans des activités qui améliorent la productivité ou la valorisation du capital existant. Dans les deux sens, elle augmente l'efficacité de la production, réduisant la consommation d'énergie. Plus précisément, lorsqu'une entreprise a accès à des financements externes, la contrainte interne devient moins un fardeau et offre potentiellement une alternative de financement pour investir dans des technologies ou des équipements afin d'augmenter la productivité. Enfin, le troisième canal, par lequel un assouplissement de la contrainte de crédit peut réduire les émissions polluantes, est tiré du modèle de Andersen (2017). Les contraintes financières faussent la composition des actifs, ce qui entrave l'acquisition d'actifs incorporels. Les actifs corporels sont positivement liés à l'émission de SO<sub>2</sub>, affirmant que la contrainte financière est préjudiciable à l'environnement.

L'objectif principal du chapitre 3 est d'évaluer si l'amélioration des conditions de crédit (dérégulation bancaire et développement financier) profite à l'environnement dans des secteurs

caractérisés par différents niveaux de vulnérabilité financière. Les émissions de polluants sont une fonction de la performance et de l'innovation de l'entreprise, tandis que le manque de financements externes (dans les secteurs vulnérables) s'avère être un facteur préjudiciable à la croissance, à l'exportation et, plus important encore, à la productivité et à l'innovation. Nous postulons que l'assouplissement de la contrainte de crédit (avec la dérégulation et la concurrence) conduit les entreprises à faire un pas en avant en termes d'innovation et de production ou d'achat de systèmes de dépollution, ce qui réduit le niveau unitaire d'émissions toxiques.

Nous utilisons deux proxys pour le développement financier et la dérégulation. Nous utilisons la variation de l'offre de crédit externe dans différentes provinces et quatre villes chinoises calculées comme la part du prêt de long terme normalisée par le PIB de la province pour estimer le développement financier. Ensuite, nous utilisons deux variables pour capturer la dérégulation bancaire calculée au niveau de la ville. Notre première approximation est mesurée par le nombre de succursales de banques commerciales de la ville au cours de l'année  $t$  dans la ville  $c$ . Notre deuxième proxy est l'inverse de l'indice Herfindahl- Hirschman (HHI). Le score varie de zéro à un, zéro indiquant le plus de réglementations et un indiquant le plus de dérégulations. Le fait est qu'une diminution dans le temps du ratio implique plus de concurrences dans les secteurs bancaires et plus de crédits fournis aux secteurs privés.

Nos résultats montrent que l'amélioration des conditions de marché est plus bénéfique pour les secteurs en difficulté financière, car ils ne peuvent pas compter sur le financement interne pour soutenir leur activité. En effet, un afflux de crédits sur le marché a un effet négatif plus important sur la pollution des secteurs en difficulté financière. Cela peut s'expliquer par le fait que l'assouplissement de l'allocation des crédits et le fait de permettre à davantage d'acteurs de financer les secteurs privés facilitent l'investissement dans la recherche et le développement ou les équipements de dépollution, réduisant les émissions sectorielles.

Nous exploitons la richesse du jeu de données du MEP pour étudier les mécanismes sous-jacents entre le développement financier et les émissions de pollution. Premièrement, l'achat

d'équipements antipollution peut être utilisé pour réduire les émissions. Deuxièmement, l'investissement dans une meilleure technologie, et enfin, une amélioration de la composition des actifs ou une réduction de la production, peuvent également affecter les émissions polluantes.

Le développement financier se caractérise par un accès moins cher au crédit et un afflux d'argent plus important, comme l'explique Chaney (2016). Dans les deux cas, on pourrait penser qu'une plus grande offre de crédit ou un accès plus facile à un prêt peuvent être utilisés pour acheter du matériel antipollution ou investir dans une technologie supérieure. Dans ce contexte, une entreprise peut choisir d'investir dans des équipements de lutte contre la pollution ou dans l'adoption de technologies. Jusqu'à présent, nous ne savons pas quel effet domine d'un point de vue théorique et si l'un ou l'autre effet a un impact statistique sur les émissions. L'effet est ambigu, car un accès moins cher au financement pourrait conduire les entreprises à investir davantage dans des équipements de lutte contre la pollution. Cependant, si une entreprise décide d'investir dans l'adoption d'une technologie qui améliore la productivité, elle réduit la consommation d'énergie en raison d'une économie sur le coût unitaire. Le canal d'adoption par la technologie réduit les émissions de pollution, ce qui, dans une certaine mesure, réduit l'incitation d'une entreprise à acheter des équipements antipollution. Dans des économies développées, Goetz (2019) montre qu'un choc financier exogène, affectant positivement l'accès au financement, a conduit les entreprises américaines à réduire leurs rejets polluants via un investissement dans les équipements antipollution, tandis que dans des économies en développement, Gutiérrez and Teshima (2018) démontre que la réduction des émissions polluantes provient du mécanisme d'adoption de la technologie. Les entreprises peuvent réduire leurs émissions grâce à une amélioration des processus à moindre coût, grâce à la mise à niveau technologique ou à de meilleures pratiques de gestion sans acheter d'équipement de réduction de la pollution (Gutiérrez and Teshima 2018). Pour mesurer l'amélioration de la technologie des usines, nous suivons Gutiérrez and Teshima (2018) et divisons l'utilisation des eaux industrielles sur les ventes. La variable suggère que

les industries avec des valeurs plus faibles ont une meilleure efficacité de production.

Les résultats montrent que les entreprises les plus contraintes financièrement ne contribuent pas à la variation des émissions de pollution résultant de l'achat d'équipements antipollution. Une explication plausible pourrait être que les managers ne priorisent pas l'aspect environnemental lorsqu'ils sont confrontés à des contraintes financières. L'acquisition de tels équipements n'affecte pas la productivité ni n'améliore les ventes. Bien au contraire, cela augmente les coûts fixes. Plus précisément, le prix des équipements de lutte contre la pollution est élevé et potentiellement hors de portée des petites et moyennes entreprises.

Une autre explication plausible peut provenir du manque d'application des lois environnementales. Des études récentes en Chine (Chen et al. 2018; He et al. 2020) et aux Etats-Unis (Evans and Stafford 2019; Goetz 2019; Karpoff et al. 2005; Shapira and Zingales 2017) ont documenté le rôle de la conformité environnementale dans le comportement d'une entreprise. Si l'application de la loi environnementale n'est pas forte et, dans une certaine mesure, la probabilité de recevoir une amende (ou une amende modeste) est faible, alors une entreprise n'a pas beaucoup d'incitations à investir massivement dans des équipements de lutte contre la pollution. Dans nos résultats, nous démontrons que l'investissement se produit dans le cadre d'une politique bien spécifique. Les entreprises ne s'y conforment que lorsqu'elles font face à des sanctions suffisamment crédibles de la part du régulateur et qu'elles acquièrent des équipements de lutte contre la pollution qui sont explicitement conformes à l'objectif de la politique. Dans le cas des villes TCZ, où l'objectif est de réduire les émissions de SO<sub>2</sub>, les entreprises se conforment en investissant dans des équipements conçus pour réduire ce type d'émissions toxiques, sans nécessairement envisager d'autres équipements de réduction des émissions d'autres polluants.

Notre deuxième de mécanisme consiste à estimer l'argument d'investissement dans des technologies suite à une amélioration de la situation financière. Les résultats complètent les conclusions de Gutiérrez and Teshima (2018) qui montrent que les entreprises réduisent leur consommation d'énergie grâce à l'adoption de technologies à la suite d'une concurrence ban-

caire accrue. L'adoption de nouvelles technologies diminue les émissions sans investissement dans des équipements de lutte contre la pollution, ce qui semble plus bénéfique du point de vue des entreprises, car la technologie améliore souvent les ventes, alors que les équipements antipollution entraînent des coûts fixes plus élevés pour une même productivité.

La distorsion des actifs peut jouer un rôle dans les émissions de pollution. Andersen (2017) a construit un modèle où l'établissement de crédit impacte indirectement les émissions polluantes. Il montre que les entreprises contraintes financent généralement des actifs corporels par le biais d'un prêt, car les banques exigent un collatéral en guise de garantie. Par extension, la distorsion de l'allocation d'actifs vers les actifs corporels est positivement corrélée aux émissions polluantes. En assouplissant la contrainte de crédit, les entreprises pourraient rééquilibrer le type d'actifs qu'elles détiennent et investir relativement moins dans le corporel au profit d'actifs incorporels. Dans cette situation, il convient de réduire les émissions de pollution. Il existe une autre façon d'assouplir les contraintes de crédit qui pourrait contribuer aux émissions polluantes. Fazzari et al. (1988) a mentionné qu'un accès moins cher au financement pourrait augmenter à la fois les investissements et la production, et sans changement dans le processus de production, nous verrions une augmentation des émissions polluantes. L'augmentation de l'échelle de production peut exercer une plus grande pression sur l'environnement, car en supposant un effet technique constant, davantage d'intrants et de ressources sont nécessaires pour satisfaire la demande accrue.

Nos résultats sont doubles. Premièrement, les résultats soutiennent le mécanisme proposé par Andersen (2017), dans lequel les entreprises contraintes ont tendance à investir relativement plus dans un actif corporel. L'assouplissement de la contrainte offre plus de flexibilité à l'entreprise dans le choix de l'actif dans lequel elle souhaite investir et, par extension, des actifs incorporels. Une réduction des investissements dans les actifs corporels au profit des actifs incorporels améliore la performance environnementale des entreprises, suite à une augmentation de la concurrence dans le secteur bancaire (c'est-à-dire la dérégulation bancaire). Deuxièmement, cela indique que le changement dans la manière dont les banques



sont réglementées ne joue pas de rôle dans le choix du niveau de production de l'entreprise. Par conséquent, nous pouvons exclure le mécanisme d'effet d'échelle dû à la dérégulation bancaire, et nous confirmons que l'adoption de la technologie joue un rôle majeur dans la réduction des émissions.

## **Le rôle de la politique industrielle dans la modernisation des produits**

Le dernier chapitre de cette thèse aborde un autre aspect du développement de la Chine. Alors que les trois premiers chapitres se concentraient sur les déterminants des émissions polluantes d'un point de vue financier, ce chapitre introduit le rôle de la politique industrielle en tant qu'outil pour motiver la modernisation des produits. Le développement économique chinois se caractérise depuis des décennies par un modèle de croissance de mauvaise qualité alimenté par la dette. Les autorités chinoises tentent de faire la transition vers une croissance plus durable sur le plan environnemental et produisant des produits de meilleure qualité, tout en supprimant les produits sales et à faible valeur ajoutée. La croissance de la Chine est également tirée par les exportations, comme le montre la figure 19.

Pour changer la structure de son économie, la Chine s'appuie largement sur les politiques industrielles, et l'un des outils préférés de Pékin, pour manipuler la composition des échanges, est le remboursement de la taxe sur la valeur ajoutée à l'exportation. Comme l'explique Feldstein and Krugman (1990), le taux de TVA, appliqué aux biens intermédiaires, doit être uniforme pour toutes les marchandises achetées sur le marché intérieur ou à l'étranger, ce qui signifie que la TVA doit être impartiale et orthogonale à la compétitivité du pays. Cependant, la Chine n'adopte pas un tel point de vue et décide de sélectionner les produits que le gouvernement souhaite promouvoir ou dont il veut freiner la production. Par exemple, l'aviation et les produits médicaux ou les secteurs high-tech appartiennent au premier type de produits, tandis que les produits consommateurs d'énergie sont censés quitter le marché

Figure 19: Exportations chinoise *versus* taux de croissance



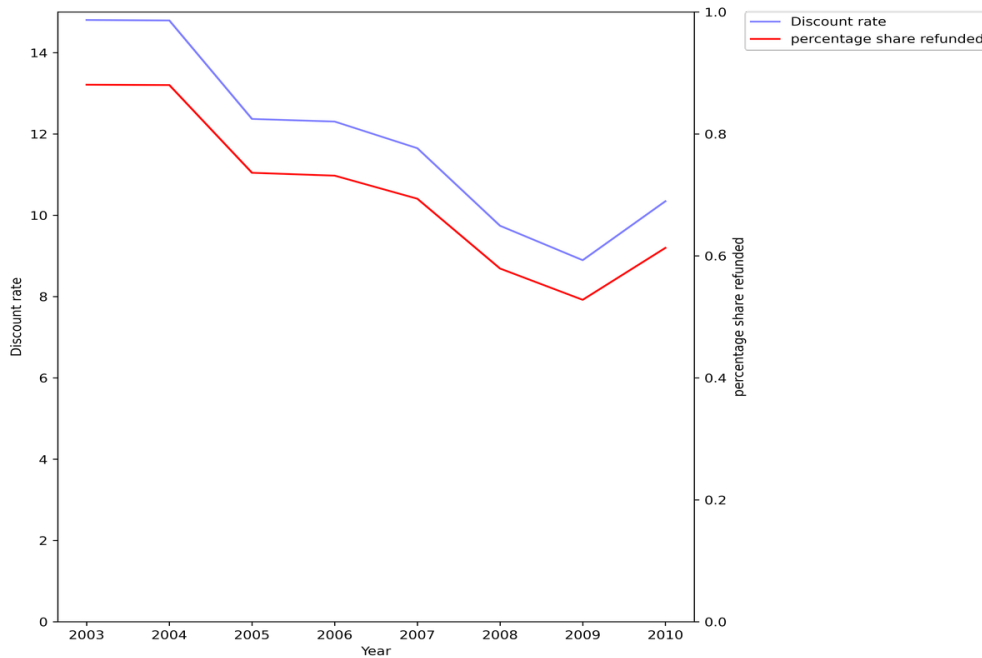
**Source:** General Administration of Customs People's Republic of China for the export data and the World bank for the economic growth rate

de l'export. En pratique, un producteur se voit attribuer un taux de base de 17%, puis l'entreprise doit consulter la circulaire n°7 (Finance Ministry and the State Administration of Taxation in China 2002) pour connaître le taux de rabais appliqué, le cas échéant. Par exemple, un produit avec un taux de TVA de 17% et un taux de rabais de 13% signifie une taxe de 4% pour l'entreprise exportatrice (ou un remboursement de 76% de la TVA). Le montant de la TVA à payer est basé sur la quantité exportée.

Le système de TVA a subi de nombreuses modifications depuis 1994. Initialement, le système servait à améliorer la compétitivité des entreprises chinoises. Depuis, le gouvernement n'a cessé d'utiliser ce levier pour promouvoir des secteurs industriels ciblés. Entre 2002 et 2006, seule une petite catégorie de produits bénéficiait d'un remboursement total de la TVA. Les remboursements de TVA affectent tous les produits de manière non uniforme. La tendance a légèrement baissé au cours de la même période, mais certains produits ont été beaucoup plus touchés que d'autres, comme le montre la figure 20. La ligne rouge (axe de gauche) indique le taux d'actualisation et la ligne bleue (axe de droite) représente la part en

pourcentage remboursée (taux d'actualisation/taux de base).

**Figure 20: Rabais de TVA au cours du temps**



**Source:** Circular No 7 from the Ministry and the State Administration of Taxation

Notre objectif est d'étudier l'effet du remboursement de la TVA sur l'amélioration des produits de 2003 à 2010. Dans une certaine mesure, l'amélioration des produits profite à la fois à l'économie et à l'environnement pour différentes raisons. Des produits de meilleure qualité atteignent des consommateurs plus aisés, prêts à payer un prix plus élevé pour des produits responsables (respectueux de l'environnement, meilleurs intrants, etc.), ce qui se traduit par une meilleure marge pour l'exportateur. En outre, des analyses transnationales au niveau de l'entreprise ont démontré principalement que les grandes entreprises facturent un prix plus élevé, en particulier sur les marchés distants, paient des salaires plus élevés et achètent des intrants de meilleure qualité pour produire des produits plus chers (Bastos and Silva 2008; Görg et al. 2017). Notre analyse est basée sur le modèle de Fan et al. (2015) où la qualité diminue avec la contrainte de crédit. Nous étendons son modèle en affirmant que le remboursement de la TVA peut atténuer les besoins de crédits, auxquels sont confrontées les entreprises contraintes, pour financer soit le coût initial plus élevé requis sur le marché

d'exportation soit en investissant dans l'innovation. En d'autres termes, la modification du remboursement de la TVA soulage les entreprises d'une charge fiscale et, par conséquent, favorise l'investissement en capital fixe, en R&D et en innovation. Les entrées de trésorerie sont alors utilisées pour investir dans des équipements, augmenter les dépenses de R&D et, par conséquent, la qualité des produits.

Le remboursement de la TVA à l'exportation est exogène pour l'exportateur, mais la qualité du produit peut ne pas l'être, ce qui contamine notre estimation. Ainsi, pour minimiser le problème d'endogénéité, nous utilisons la dualité du système commercial pour différencier les flux d'exportation entre les exportateurs "ordinaires" et les exportateurs "transformateurs". En Chine, les exportateurs peuvent opter pour l'un de ces deux régimes en fonction de leurs objectifs. Le commerce ordinaire est le type le plus courant pour les entreprises exportatrices. Le commerce ordinaire signifie que l'entreprise paie la taxe à l'importation et à l'exportation, y compris le remboursement de la TVA, selon la méthode "exemption, crédit et remboursement". Le commerce de "transformation" joue un rôle différent dans le commerce international. L'objectif principal est d'importer des matières premières, des composants ou des intrants intermédiaires de l'étranger et de les assembler et les réexporter. Les entreprises étrangères reconnaissent l'extrême commodité de ce type de commerce. Le gouvernement chinois accorde des avantages substantiels aux entreprises étrangères qui choisissent ce statut, à savoir des importations en franchise de droits et une baisse de l'impôt sur les sociétés. La méthode "pas de collecte et pas de remboursement" empêche les exportateurs transformateurs de demander des remboursements. Les responsables politiques considèrent que les entreprises ne possèdent pas de capital ni aucune autre forme d'actif. Nous supposons donc que seuls les exportateurs ordinaires devraient réagir à une modification du remboursement de la TVA et, en réponse, affecter la mise à niveau du produit. Cette stratégie d'estimation est nouvelle puisque la littérature s'est concentrée sur l'effet de la libéralisation des échanges, en utilisant la réduction de la taxe à l'importation, pour évaluer le changement de prix du produit (Bas and Strauss-Kahn 2015), mais ignore

le changement de qualité d'une taxe à l'exportation. Nous nous appuyons également sur un nouvel indicateur pour mieux capter la qualité.

Des études antérieures (Hallak 2006) utilisaient le prix unitaire pour expliquer les variations des prix internationaux, en supposant qu'un prix plus élevé est synonyme de meilleure qualité. Le défaut du prix unitaire est qu'il rend compte de la différence des coûts de production à travers le pays, ce qui ne se traduit pas forcément par une meilleure qualité. La méthodologie de Khandelwal (2010), contrairement au prix unitaire, se concentre sur les composantes verticales de la qualité. Une autre particularité de cet indice est qu'il est très flexible; on peut estimer la qualité d'un produits pour les deux types de commerce, selon le pays importateur. Le régime commercial est au cœur de notre stratégie, et la qualité reflète l'évolution du mix de production au sein d'une ville.

Nos résultats suggèrent une augmentation de la mise à niveau du produit en réponse à une augmentation du remboursement de la TVA. L'effet économique est important. Une augmentation du remboursement de 10 points de pourcentage augmente la mise à niveau du produit d'environ 26% pour les entreprises éligibles, celle-ci dépendant largement de l'industrie et du pays de destination. Nos résultats montrent également que les exportateurs ordinaires se conforment aux réglementations des pays importateurs. L'utilisation de barrières non commerciales pour élever la norme du pays d'importation pousse l'exportateur ordinaire à augmenter la qualité. Nous confirmons ces résultats en montrant que les grandes industries exportent des biens de meilleure qualité que les plus petites. Le modèle montre un différentiel de 7 points de pourcentage dans la mise à niveau du produit, suite à une augmentation de la remise pour les grandes industries par rapport aux petites industries. Enfin, nous étudions la différence de goût en fonction du revenu du pays de destination. Les preuves empiriques montrent que les pays les plus riches consomment davantage de produits de haute qualité, ce qui est confirmé dans nos estimations. Les exportateurs augmentent la qualité, en réponse à une variation positive du rabais, lorsque le marché de destination a un revenu plus élevé. Les exportateurs peuvent profiter d'un changement positif de la

remise pour initier une mise à niveau du produit et pénétrer des marchés plus rentables mais exigeants. En outre, les résultats correspondent à la prédiction du modèle de Fan et al. (2015), où des contraintes de crédits plus strictes obligent les entreprises à produire une qualité inférieure. Nous étendons son modèle selon lequel une augmentation de la ristourne accordée aux exportateurs ordinaires, les entreprises utilisent cet excédent de trésorerie pour investir (dans une immobilisation ou un projet innovant) en améliorant la qualité.

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# Chapter 1

## Description of the annual survey of Chinese enterprises

## 1.1 Introduction

Our primary data source for this thesis is the annual survey of Chinese enterprises collected by the Ministry of Environmental Protection (MEP hereafter) over the 1998-2007 period. The MEP has monitored firms in 39 major industrial sectors considered to be heavy polluters. These firms are asked to report basic information, such as company name, address, and output. They also answer a detailed questionnaire about their emissions of major pollutants (e.g., wastewater, COD, SO<sub>2</sub>, industrial smoke, and dust). As reported by Wu et al. (2017) and Jiang et al. (2014), this dataset contains about 85% of the industrial pollution emissions from major pollutants in China. The MEP has implemented strict procedures, including unforeseen expert visits, to ensure that these firms do not misreport their emissions.

The dataset contains numerous information about the firm's toxic emissions, pollution abatement equipment, and energy consumption by energy type (coal, natural gas, diesel fuel, heavy oil). In table 1.1, we provide a list of the variables contained in the dataset and their definitions.

## 1.2 Dataset preparation

Adjustments were necessary to prepare the dataset. First, the pollution dataset reports CIC code using the 1994 version and the 2002 revision. All firms are required to use the new codes after 2002 to allow for comparison over time. However, in many cases, this condition was not respected. We observed firms using the pre-2002 CIC codes after 2002. To overcome this issue, we use the concordance table from Brandt et al. (2012)<sup>1</sup>. We also merged the industry name using the official website from the NBS<sup>2</sup>.

We excluded industry 38, which was removed in the 2002 revision. For this chapter, we kept the CIC codes that are not matched in the concordance table 1994/2002, to have a firm level pollution emission dataset as close to the official values released by the Ministry

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<sup>1</sup>The data is available <https://sites.google.com/view/jovb/data-programs>

<sup>2</sup>Official link NBS

**Table 1.1: Variables definition**

|    | Name                              | Type   | Comment   |
|----|-----------------------------------|--------|---|
| 0  | year                              | string | year  |
| 1  | citycode                          | string | <i>citycode</i> refers to city ID, more commonly known as <i>geocode4corr</i> |
| 2  | prov2013                          | string | Province name in Chinese  |
| 3  | pref2013                          | string | Prefecture name.  |
| 4  | <i>indus_code</i>                 | string | 4 digits industry code  |
| 5  | ind2                              | string | 2 digits industry code  |
| 6  | ttoutput                          | float  | Total output city sector (in 10.000 yuan)                                     |
| 7  | <i>twaste_water</i>               | int    | Total waste water city sector (in ton)  |
| 8  | tcod                              | float  | Total COD city sector (in kg)   |
| 9  | <i>tammonia_nitrogen</i>          | float  | Total Ammonia Nitrogen city sector (in kg)                                    |
| 10 | <i>twaste_gas</i>                 | int    | Total Waste gas city sector (in kg)   |
| 11 | tso2                              | int    | Total so2 city sector (in kg)   |
| 12 | tnox                              | int    | Total NOx city sector (in kg)   |
| 13 | <i>tsmoke_dust</i>                | int    | Total smoke dust city sector (in kg)  |
| 14 | tsoot                             | int    | Total soot city sector (in kg)  |
| 15 | tlssnl                            | int    | Desulfurization capacity (kg/h)   |
| 16 | <i>tdwastegas_equip</i>           | int    | The number of equipment of removing wasted gas                                |
| 17 | <i>tdso2_equip</i>                | int    | The number of equipment of removing so2                                       |
| 18 | tfqzlssnl                         | int    | The capacity to remove wasted gas cube meter/hour                             |
| 19 | ttlssnl                           | int    | The capacity to remove so2 kilogram/hour                                      |
| 20 | firdmum                           | int    | The number of firms ith equipment in city-industry-year                       |
| 21 | tfirm                             | int    | The number of firms ith equipment in city-year                                |
| 22 | <i>tlssnl_output</i>              | float  | The number of firms ith equipment in city-year divided by the output          |
| 23 | <i>tdwastegas_equip_output</i>    | float  | The number of equipment of removing wasted gas per unit of output             |
| 24 | <i>tdso2_equip_output</i>         | float  | The number of equipment of removing so2 per unit of output                    |
| 25 | <i>total_industrialwater_used</i> | int    | Total industrial water used (in tons)   |
| 26 | <i>total_freshwater_used</i>      | int    | Total freshwater used (in tons)   |
| 27 | <i>total_repeatedwater_used</i>   | int    | Total repeated water used (in tons)   |
| 28 | <i>total_coal_used</i>            | int    | Total coal used (in tons)   |
| 29 | trlmxf                            | int    | The consumption of fuel coal  |
| 30 | tylmxf                            | int    | The consumption of raw coal (in tons)   |
| 31 | <i>clean_gas_used</i>             | int    | Clean gas used (in 10.000 cubic meters)                                       |
| 32 | <i>dwastewater_equip</i>          | int    | Wastewater equipment  |
| 33 | tfszlssnl                         | int    | The capacity to remove wasted water ton/day                                   |
| 34 | tfszlssfee                        | int    | The expense to remove wasted water ton/day                                    |

The dataset comes from the annual survey of Chinese enterprises collected by the Ministry of Environmental Protection over the 1998-2007 period.

of Ecology and the Environment (MEE) as possible. The other thesis chapters used only the manufacturing industries matched with the concordance table. The data provides information on the major pollutants in 356 cities, 30 provinces/municipalities, and 30 industries (2-digits) during ten consecutive years.<sup>3</sup>

### 1.3 Dataset reliability

The MEP does not survey all the firms in China. We might be concerned about the representativeness of the dataset against the official pollution emissions released annually by the Ministry of Ecology and the Environment. More precisely, the MEP surveys firms from the top 80 percentiles of the firm-level pollution distribution each year. To ensure, we compared the aggregated values from the firm’s survey with the true figures of the Chinese Ministry of Ecology and the Environment. The official data is only available in the *Chinese* version of the reports.<sup>4</sup> For instance, to get the official record for the SO<sub>2</sub> emission in 1999, we had to use the PDF for year 1999<sup>5</sup> and go to page 15 (see figure 1.1). We replicated this exercise for our three main pollutants: SO<sub>2</sub>, COD, and wastewater.

The dataset from the MEP includes all industrial firms, meaning it deals with industries from the primary, secondary, and third sectors. A reader unfamiliar with this dataset and literature, in general, can easily get confused. The literature implicitly assumes the reader only knows that the secondary sectors are used. Some papers also confused the reader with the terminology and the statistics displayed. For instance, in Rodrigue et al. (2022), the researchers indicate they use the ”sulfur dioxide emissions among Chinese *manufacturers* during the WTO accession period.” and ”Mapping this data to corresponding production surveys and balance-sheet data we investigate the seemingly muted response of Chinese emissions to the expansion of the *manufacturing sector*.” In figure 1.1, they plot the official

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<sup>3</sup>We do not have the firm-level data because the data is too sensitive and difficult to share. For all chapters, we use the city-industry-year level.

<sup>4</sup>To find the data, it was necessary to open each report from this website <https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/index.shtml>

<sup>5</sup><https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/201605/P020160526551374320882.pdf>

Figure 1.1: Report on the State of the Ecology and Environment in China

1999 年与 1998 年废气中主要污染物排放状况对比单位 (万吨)

| 年度     | 二氧化硫 <span style="color: red;">Industrial emission</span> |       |        | 烟尘    |       |        |
|--------|---|-------|--------|-------|-------|--------|
|        | 工业  | 生活    | 总量     | 工业    | 生活    | 总量     |
| 1999 年 | 1460.1  | 397.4 | 1857.5 | 953.4 | 205.6 | 1159.0 |
| 1998 年 | 1594  | 497   | 2091   | 1179  | 276   | 1455   |
| 增减率(%) | -8.4  | -20   | -11.2  | -19.1 | -25.7 | -20.3  |

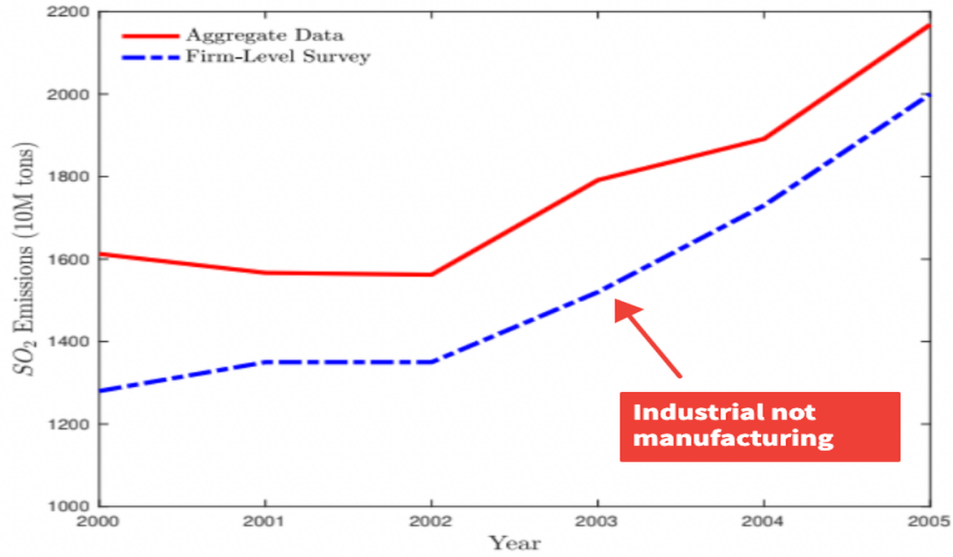
**Note:** The table indicates how to extract official emission figures from the Ministry of Ecology and Environment. The data is only available from the Chinese version of the report. **Source:** The PDF is available from the Ministry of Ecology and Environment of the People’s Republic of China.

industrial SO2 emission and the aggregated value from their firm-level survey.

However, the researchers effectively plot the industrial SO2 emission, not the manufacturing subset. To avoid confusion, we replicated this graph for each of the three main pollutants and distinguish between the firm-level survey industrial values, and the firm-level survey manufacturing values and the official industrial pollution emission from the Chinese Ministry of Ecology. In table 1.2, we summarize all the 2-digits codes for each industry class from the official NBS nomenclature.<sup>6</sup> In the appendix, we’ve included the official industrial classification from the NBS (table 1.7). The manufacturing 2-digits codes go from 13 to 43.

<sup>6</sup>Regulations on Industrial Classification

Figure 1.2: Confusion between industrial *versus* manufacturing SO2 emissions



(a)  $SO_2$  Emissions Over Time

**Note:** The figures plot the annual emissions of  $SO_2$  (in 10M tons). The solid red represents the value reported by MEE in annual reports, while the dashed blue line represents the aggregated value from the firm-level survey. **Source:** The figure comes from Rodrigue et al. (2022).

**Table 1.1: Regulations on Industrial Classification- 2 digits per industrial class**

| industry class  | CIC two-digits 2002-revision   |
|---|--|
| 0 Accommodation and food industry   | [66, 67]   |
| 1 Construction industry   | [47, 48, 49, 50]   |
| 2 Cultural, physical and entertainment industry                             | [88, 89, 90, 91, 92]   |
| 3 Education   | [84]   |
| 4 Farming, forestry, animal husbandry and fishery                           | [01, 02, 03, 04, 05]   |
| 5 Finance industry  | [68, 69, 70, 71]   |
| 6 Information transfer, computer service and software industry              | [60, 61, 62]   |
| 7 International organizations   | [98]   |
| 8 Leasehold and business service industry                                   | [73, 74]   |
| 9 Manufacturing industry  | [13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43] |
| 10 Mining industry  | [06, 07, 08, 09, 10, 11]   |
| 11 Neighborhood services and other service industry                         | [82, 83]   |
| 12 Production and supply of electric power, gas and water                   | [44, 45, 46]   |
| 13 Public administration and social organization                            | [93, 94, 95, 96, 97]   |
| 14 Realty business  | [72]   |
| 15 Sanitation, social security and social welfare industry                  | [85, 86, 87]   |
| 16 Scientific research, technical service and geologic examination industry | [75, 76, 77, 78]   |
| 17 Traffic, storage and mail business                                       | [51, 52, 53, 54, 55, 56, 57, 58, 59]   |
| 18 Water conservancy, environment and public institution management         | [79, 80, 81]   |
| 19 Wholesale and retail trade   | [63, 65]   |

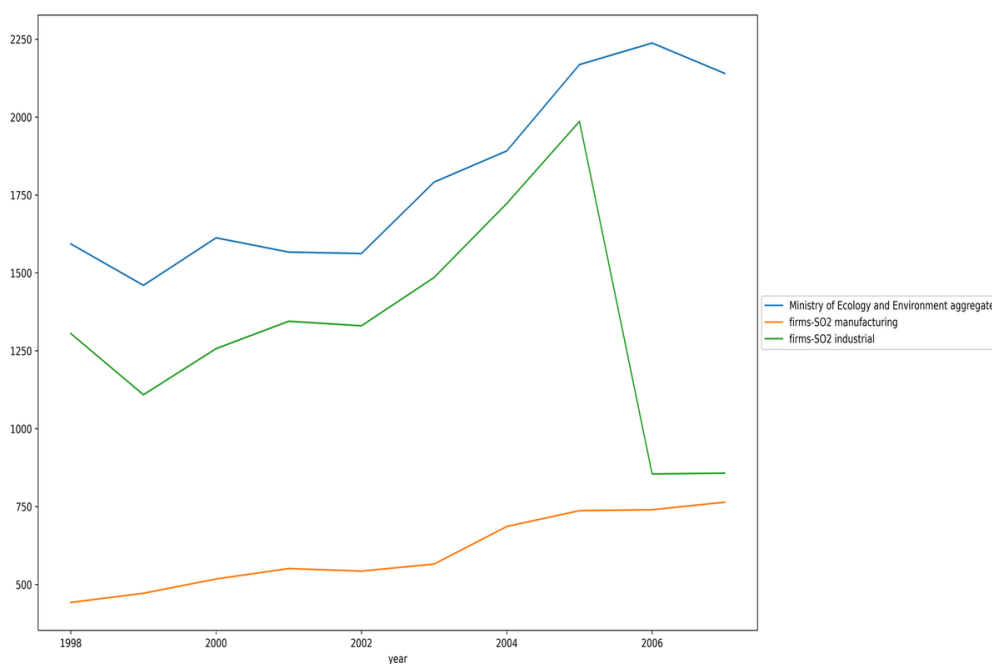
The data comes from the NBS website.



### 1.3.1 Comparison MEP official industrial pollution emission *versus* firm survey's industrial values

In figure 1.3, we plot the Ministry of Ecology and Environment aggregate values of SO<sub>2</sub> (in blue), the firm survey's industrial values (in green), and the firm survey's manufacturing values (in orange). Even though the values from the official data and the firm's survey are noticeably different, the trend remains the same; there is a large drop in the industrial SO<sub>2</sub> emission after 2005 because the thermal factories are no longer included in the dataset.

**Figure 1.3: Industrial official *versus* firm's survey industrial *versus* firm's survey manufacturing industry SO<sub>2</sub> emissions**



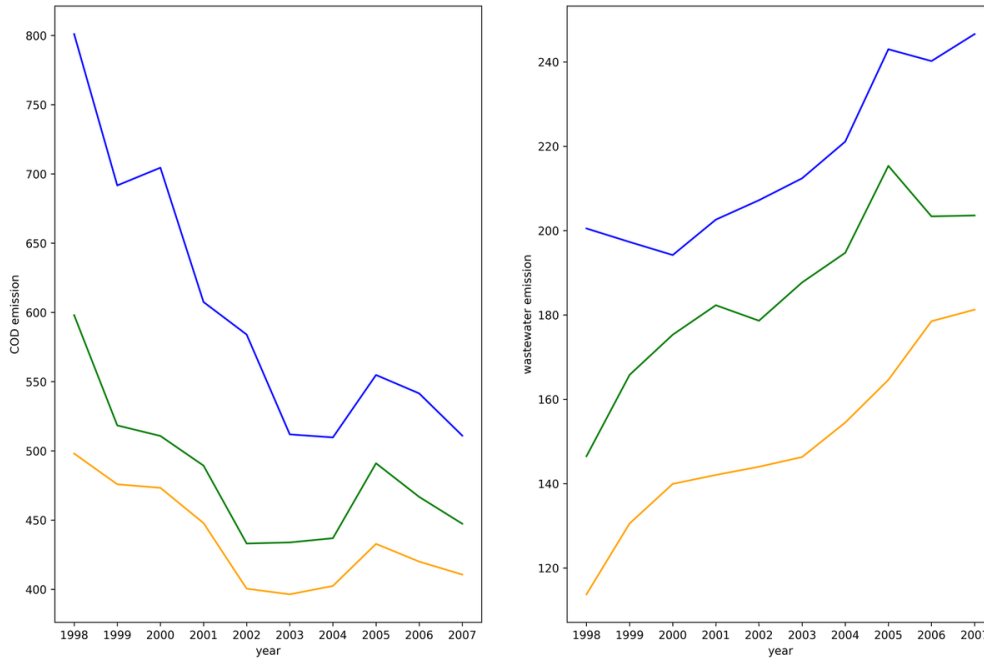
**Note:** The figure plots annual emissions of SO<sub>2</sub> (in 10M tons) based on the official industrial emission, firm's level industrial emissions and firm's level manufacturing emissions. The blue line represents the value reported by MEE in annual reports, the green line represents the value of the industrial emission reported by the firm's level survey, and the orange line represents the aggregated value from the manufacturing industry firm-level survey. **Source:** The official industrial SO<sub>2</sub> emissions come from the MEE annual *Report on the State of the Ecology and Environment in China*, and the firm level data come from the annual survey conducted by the MEP.

In Rodrigue et al. (2022), they capture 79% of the official values whereas we capture

78%. The percentage remains closely equivalent for the remaining years, around 85% to 92%. Hence, we can confirm that the authors use the industrial data, not the manufacturing data, although they use the term manufacturing to describe their dataset. To avoid any confusion in this thesis, we use the manufacturing codes only (from 13 to 43), and we use the term "industry" and "manufacturing" equivalently as in the literature.

We reconducted the same analysis for the wastewater and COD emissions in figure 1.4. The difference is perceptible, but the trend and the percentage captured by the firm survey are roughly the same.

**Figure 1.4: Industrial official *versus* firm’s survey industrial *versus* firm’s survey manufacturing industry COD/wastewater emissions**



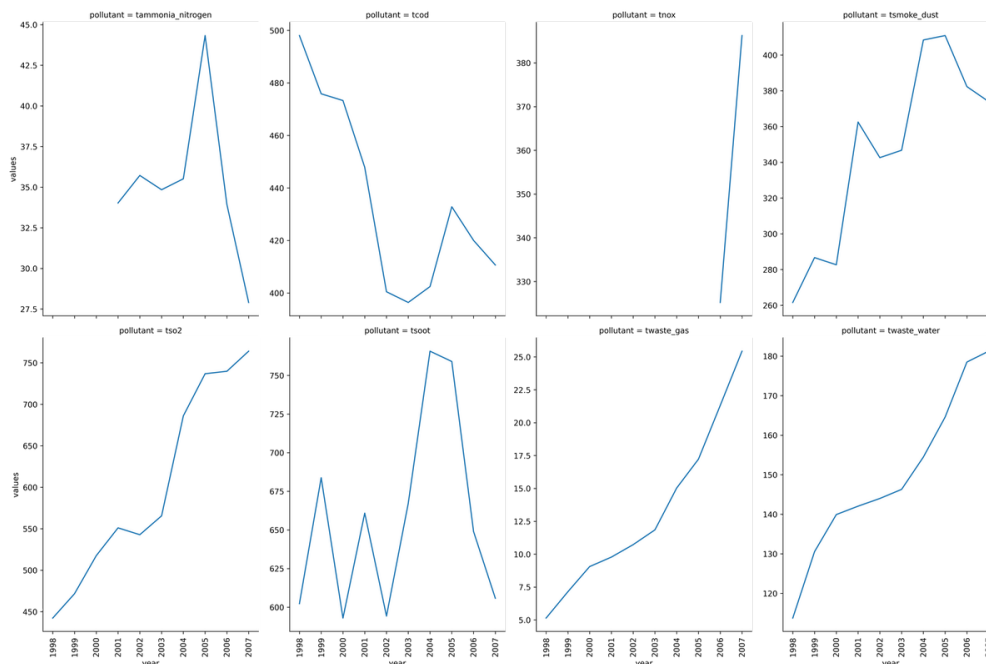
**Note:** The figure plots annual emissions of COD (in 10M tons)/wastewater (in 100M tons) based on the official industrial emission, firm’s level industrial emissions, and firm’s manufacturing emissions. The blue line represents the value reported by MEE in annual reports, the green line represents the value of the industrial emission reported by the firm’s level survey, and the orange line represents the aggregated value from the manufacturing industry firm-level survey. **Source:** The official industrial COD/wastewater emissions come from the MEE annual *Report on the State of the Ecology and Environment in China*, and the firm-level data come from the annual survey conducted by the MEP.

## 1.4 Pollution emissions, technology and pollution abatement equipment

As we mentioned earlier, the dataset reports different information such as the location of each firm, the output, the toxic emission discharged, and the consumption by energy type.

In figure 1.5, we plot the yearly aggregated values of the different pollutants, such as wastewater, COD, SO2, soot, nox, smoke, and waste gas. The emission of COD decreased substantially over the period. However, the other pollutants displayed different trends: SO2, wastewater, waste gas, and smoke have increased substantially over time.

**Figure 1.5: Manufacturing emission of pollutant in China**

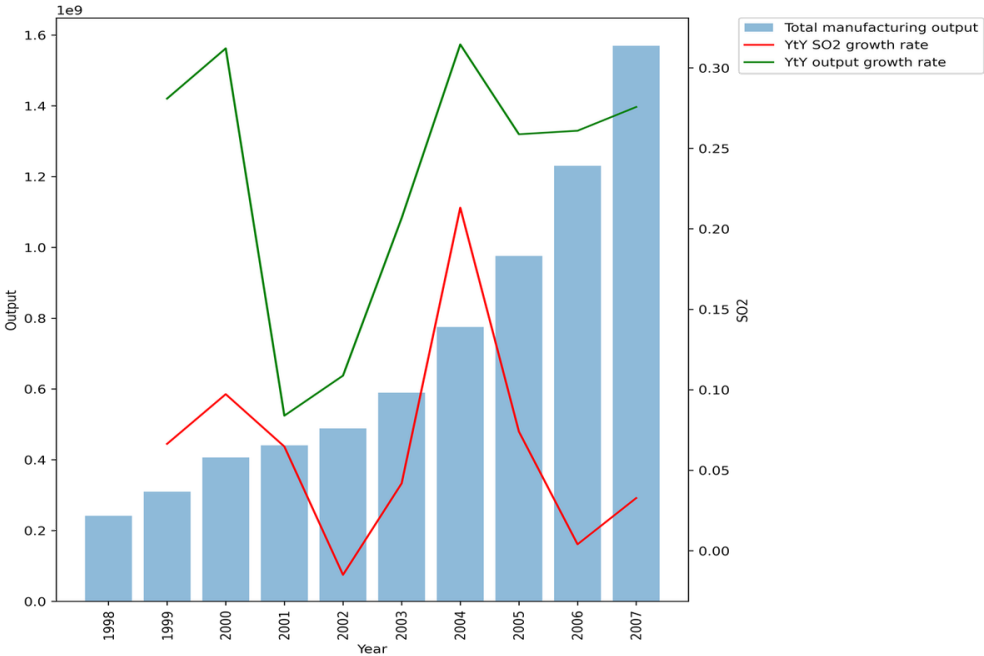


**Note:** Wastewater and waste gas are in 100M tons. COD, Nitrogen, SO2, Nox, Smoke and Soot are in 10M tons. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

SO2 emissions in China had not peaked yet during the period covered by our analysis (1998 to 2000). The upward trend continued until 2010 when the SO2 emission reached a turning point. The chart below (figure 1.6) presents evidence that SO2 emissions did not

grow nearly as fast as the manufacturing output. The bar represents the manufacturing output, the green line the percentage change over time, and the red line the year-to-year change of SO2 emission. The output was five times larger in 2007 from 1998, while SO2 emission was 72% higher in 2007 compared with 1998. The correlation between the percentage change of manufacturing output and the percentage change of SO2 emission is 50%. The evidence suggests that the capital of the manufacturing sector went through substantial progress. Otherwise, we would have seen a 1-to-1 correlation between production and SO2 emissions. Different factors like technological changes, scale economy, changing attitudes toward environmental concern (ESG), and policy and regulation appear to impact the pattern of pollution emissions directly. Ultimately, reducing SO2 emissions (and any other pollutants) depends on the capacity of a firm to adopt technologically-superior capital and the country's political choices through stringent environmental regulations.

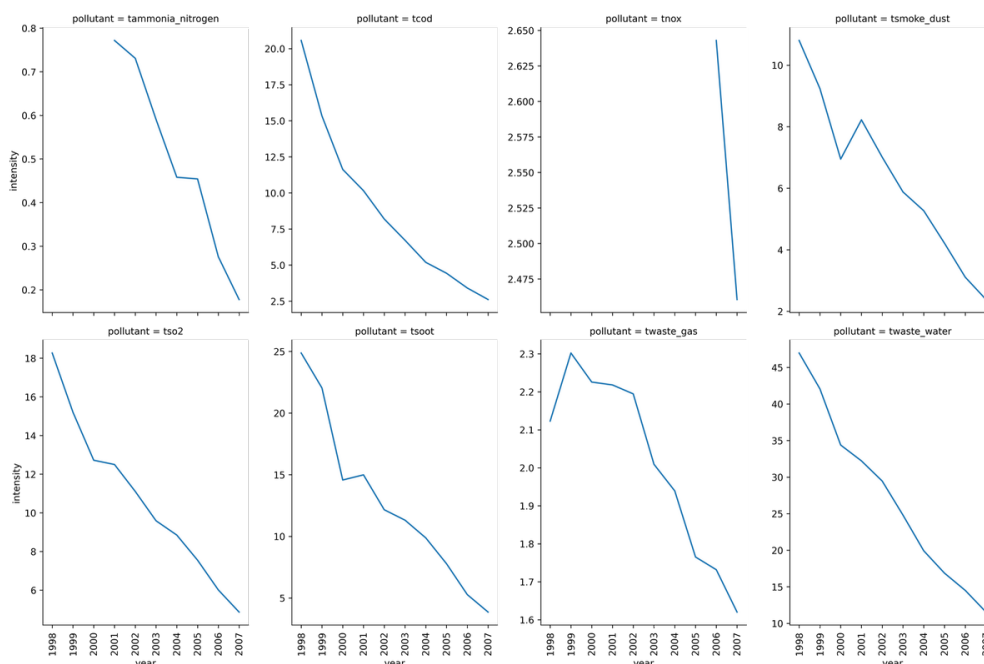
**Figure 1.6: Total manufacturing output and year-to-year change of SO2 emission**



**Note:** The blue bar represents the total manufacturing output, the green line represents the YtY output growth rate, and the red line the YtY change of SO2 emission (in 10M tons). **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

Reducing pollution emissions from a technology change is referred to as energy efficiency gains. This reduction can be attributed to cost-saving or productivity improvement. To determine if the pollution pattern comes from a change in productivity, we divided each pollutant by the sector output. It is clear that figure 1.7 supports the assertion of the energy efficiency gain argument by illustrating that the emission of all pollution intensity has decreased over time.

**Figure 1.7: Pollution intensity and energy efficiency gain**

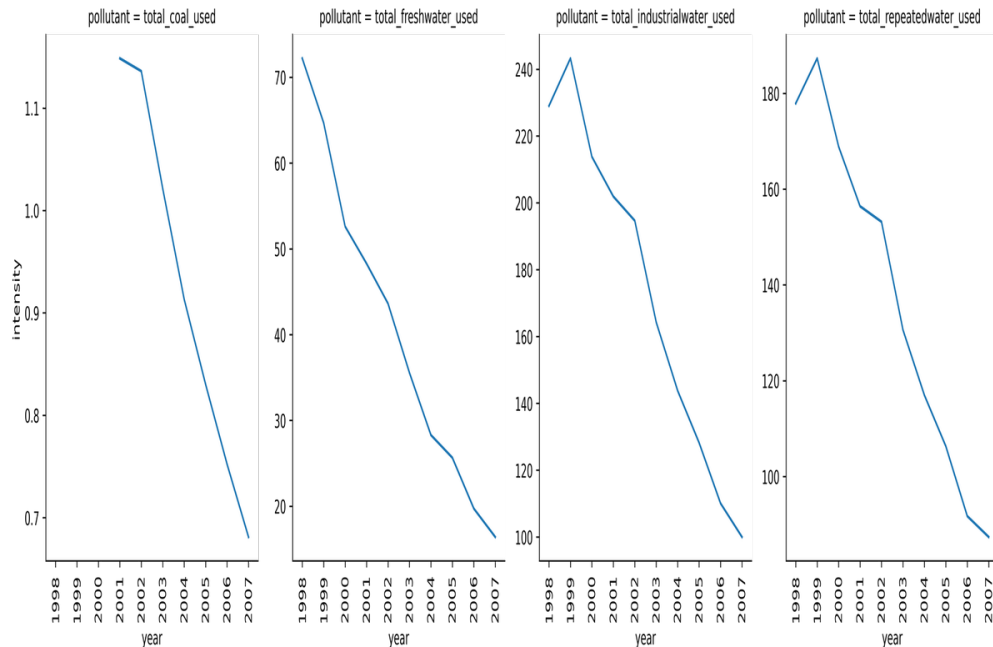


**Note:** The graph plots the ratio of pollutants divided by the total manufacturing output. Lower values indicate better management of resources because fewer emissions are emitted per unit of output. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

There are two possible reasons to explain better pollution over output ratio. First, when a firm invests in technology adoption, it often induces lower energy use per unit of output through better productivity and management of resources. Second, a firm can invest in pollution abatement equipment. To measure the improvement in plants' general technology, we follow Gutiérrez and Teshima (2018) and divide the total use of the sector's industrial

water by sector's sales. We also use the total coal use, freshwater, and repeated water divided by sales to provide further evidence of the technology adoption argument. The variable suggests that industries with lower values have a better production efficiency. Figure 1.8 plots the technology adoption argument. We can, unquestionably, see a decreasing trend, possibly implying that firms have invested in technology that would have improved the production process.

**Figure 1.8: Technology adoption**



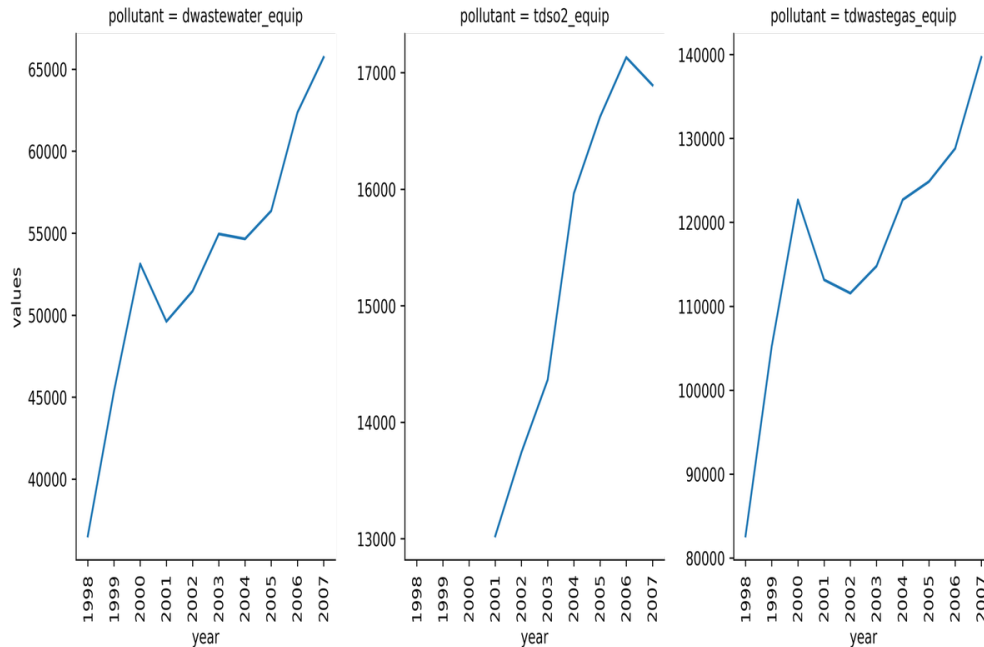
**Note:** The graph plots the plants' general technology by following Gutiérrez and Teshima (2018) and dividing the total use of industrial water (and other pollutants) over sales.

**Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

We plotted the stock of pollution abatement equipment (wastewater, SO<sub>2</sub>, and waste gas equipment) to evaluate the second possible mechanism through which pollution intensity has decreased. The number of firms investing in pollution abatement equipment rose by 30% between 2001 and 2007 from 6232 to 8899. The stock of equipment also expended substantially (figure 1.9). However, when we look at the ratio of equipment/pollution, it is

very low. Pollution abatement equipment does not appear to be as successful as technology adoption in terms of explaining the improvement of pollution intensity. China will likely require innovation across many sectors to significantly reduce pollution.

**Figure 1.9: Stock of pollution abatement equipment**



**Note:** The graph plots the count of pollution abatement equipment per year. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

## 1.5 Data description by sector

Whilst the aggregate country-level trends are interesting, in this thesis, we are concerned with inspecting pollution patterns at the industry level. In table 1.3, we compute the aggregate COD emissions for each of the 30 industries from 1998 to 2007. The numbers in parenthesis indicate the year-to-year percentage change. The table is sorted according to the highest polluting sectors in 2007. The *Papermaking and paper product industry* was the largest COD emitter in 2007, with 1,574 million tons. This is more than twofold the amount of the second largest polluting industry, *Manufacturing of agricultural and non-staple foodstuff*.

**Table 1.3: Yearly sectoral change of COD emissions**

| CIC two-digits | 2002-revision | name  | 1998      | 1999         | 2000         | 2001          | 2002          | 2003          | 2004         | 2005         | 2006          | 2007         | average YY change | change 98-07 | sum period |            |
|----------------|---------------|---|-----------|--------------|--------------|---------------|---------------|---------------|--------------|--------------|---------------|--------------|-------------------|--------------|------------|------------|
| 0              | 22            | Papermaking and paper product industry  | 182.8 (-) | 205.6 (0.12) | 210.0 (0.02) | 194.2 (-0.08) | 152.3 (-0.08) | 147.2 (-0.03) | 148.5 (0.01) | 160.1 (0.08) | 156.7 (-0.02) | 157.4 (0.0)  | -0.01             | -0.23        | 171.04279  |            |
| 1              | 33            | Manufacturing of agricultural and non-staple foodstuff  | 75.9 (-)  | 74.0 (-0.02) | 69.8 (-0.06) | 57.0 (-0.18)  | 61.1 (0.21)   | 66.7 (0.03)   | 62.9 (-0.06) | 69.9 (0.11)  | 62.0 (-0.11)  | 60.2 (-0.03) | -0.02             | -0.19        | 607.66234  |            |
| 2              | 34            | General foodstuff and chemical manufacturing industry   | 23.2 (-)  | 23.0 (0.0)   | 22.5 (0.02)  | 22.0 (0.01)   | 24.8 (0.08)   | 24.2 (0.02)   | 20.5 (-0.21) | 26.8 (-0.01) | 31.1 (0.07)   | 31.5 (0.05)  | 0.06              | 0.65         | 261.90751  |            |
| 3              | 17            | Textile industry  | 28.8 (-)  | 30.9 (0.01)  | 29.1 (-0.04) | 32.9 (0.01)   | 23.8 (-0.08)  | 24.8 (0.08)   | 24.8 (0.08)  | 29.4 (0.21)  | 28.8 (-0.01)  | 22.2 (0.18)  | 22.8 (0.03)       | -0.01        | -0.25      | 251.558066 |
| 4              | 15            | Beverage manufacturing industry   | 28.9 (-)  | 30.4 (0.06)  | 29.1 (-0.04) | 38.0 (0.24)   | 23.4 (-0.05)  | 20.8 (-0.11)  | 19.4 (-0.07) | 17.4 (0.09)  | 17.7 (0.09)   | 13.4 (-0.1)  | 0.01              | -0.20        | 147.350597 |            |
| 5              | 32            | Ferrous metal smelting and extrusion  | 12.9 (-)  | 18.4 (0.32)  | 14.6 (-0.2)  | 13.9 (-0.04)  | 14.3 (-0.06)  | 19.3 (0.4)    | 16.0 (0.19)  | 14.3 (-0.26) | 14.8 (-0.05)  | 12.4 (0.06)  | 0.01              | -0.32        | 145.88843  |            |
| 6              | 27            | Medicine manufacturing industry   | 13.9 (-)  | 18.4 (0.32)  | 14.6 (-0.2)  | 14.0 (-0.04)  | 13.8 (-0.02)  | 19.3 (0.4)    | 14.3 (-0.26) | 14.3 (-0.26) | 13.4 (-0.07)  | 11.8 (-0.12) | 0.00              | -0.32        | 116.451584 |            |
| 7              | 14            | Foodstuff manufacturing industry  | 12.1 (-)  | 15.8 (0.31)  | 14.3 (-0.1)  | 10.1 (-0.29)  | 10.0 (-0.01)  | 9.9 (-0.01)   | 10.6 (0.07)  | 12.0 (0.14)  | 10.9 (-0.09)  | 10.8 (-0.01) | 0.00              | -0.22        | 116.88464  |            |
| 8              | 28            | Chemical fiber manufacturing industry   | 11.2 (-)  | 12.7 (0.13)  | 15.6 (0.24)  | 15.6 (-0.0)   | 10.6 (-0.32)  | 10.6 (-0.0)   | 8.9 (-0.16)  | 10.4 (0.18)  | 11.5 (0.1)    | 9.8 (-0.14)  | 0.00              | -0.04        | 81.368498  |            |
| 9              | 25            | Petroleum processing, coking and nuclear fuel manufacture   | 22.5 (-)  | 7.1 (-0.68)  | 5.5 (-0.23)  | 5.8 (0.07)    | 5.7 (-0.02)   | 4.9 (-0.14)   | 5.8 (0.17)   | 8.4 (0.44)   | 7.4 (-0.11)   | 8.2 (0.11)   | 0.01              | 0.56         | 69.352940  |            |
| 10             | 19            | Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products          | 9.6 (-)   | 4.5 (-0.32)  | 7.6 (0.67)   | 6.7 (-0.11)   | 6.4 (-0.06)   | 5.9 (-0.07)   | 6.8 (0.14)   | 7.6 (0.11)   | 5.9 (-0.22)   | 4.5 (-0.25)  | 0.01              | 0.37         | 82.60264   |            |
| 11             | 31            | Non-ferrous smelting and extrusion  | 38.9 (-)  | 3.3 (-0.02)  | 2.8 (-0.13)  | 6.5 (1.29)    | 6.4 (-0.02)   | 4.0 (-0.37)   | 5.4 (0.37)   | 4.9 (-0.1)   | 4.5 (0.32)    | 3.1 (-0.3)   | 0.18              | 1.06         | 29.23004   |            |
| 12             | 33            | Non-ferrous smelting and extrusion  | 1.9 (-)   | 1.5 (0.03)   | 1.9 (0.26)   | 4.5 (1.36)    | 2.5 (-0.45)   | 3.4 (0.36)    | 2.8 (-0.16)  | 3.4 (0.21)   | 4.5 (0.32)    | 3.1 (-0.3)   | 0.28              | 2.30         | 13.323630  |            |
| 13             | 34            | Metals and metal products manufacturing industry  | 0.5 (-)   | 0.8 (0.71)   | 0.8 (-0.07)  | 0.9 (0.16)    | 1.1 (0.22)    | 1.2 (0.11)    | 1.4 (0.18)   | 2.0 (0.4)    | 1.7 (0.14)    | 2.5 (0.6)    | 0.21              | 2.49         | 13.323630  |            |
| 14             | 30            | Transportation, communication facilities manufacturing industry                                   | 9.1 (-)   | 9.1 (0.0)    | 9.1 (0.0)    | 9.1 (0.0)     | 9.1 (0.0)     | 9.1 (0.0)     | 9.1 (0.0)    | 9.1 (0.0)    | 9.1 (0.0)     | 9.1 (0.0)    | 0.0               | 0.0          | 9.1        |            |
| 15             | 39            | Transportation, communication facilities manufacturing industry                                   | 0.6 (-)   | 0.7 (0.09)   | 1.2 (0.8)    | 1.3 (0.12)    | 1.1 (-0.26)   | 1.6 (0.59)    | 1.5 (-0.01)  | 1.7 (0.08)   | 1.9 (0.17)    | 2.6 (0.39)   | 0.21              | 2.08         | 13.986389  |            |
| 16             | 18            | Manufacturing industry of textile costumes, shoes and caps  | 0.3 (-)   | 0.5 (0.86)   | 0.8 (0.5)    | 0.4 (-0.5)    | 0.4 (0.37)    | 0.7 (0.38)    | 1.4 (0.9)    | 2.1 (0.53)   | 1.7 (-0.17)   | 1.8 (0.12)   | 0.32              | 2.43         | 10.234383  |            |
| 17             | 20            | Wood processing and manufacturing industry of wood, bamboo, rattan, palm, and straw-made articles | 3.4 (-)   | 3.8 (0.1)    | 3.3 (-0.12)  | 1.9 (-0.43)   | 2.1 (0.1)     | 2.5 (0.23)    | 3.4 (0.34)   | 2.8 (-0.18)  | 2.2 (-0.22)   | 1.6 (-0.26)  | -0.05             | -0.57        | 27.024075  |            |
| 18             | 35            | General-purpose equipment manufacturing industry  | 1.2 (-)   | 1.5 (0.23)   | 1.6 (0.13)   | 1.6 (0.0)     | 1.6 (-0.03)   | 1.3 (-0.17)   | 1.3 (-0.02)  | 1.7 (0.36)   | 2.4 (0.36)    | 1.6 (-0.33)  | 0.06              | 0.10         | 15.842729  |            |
| 19             | 40            | Manufacturing industry of communication equipment, computers and other electronic equipment       | 0.5 (-)   | 0.7 (0.4)    | 0.8 (0.08)   | 1.2 (0.5)     | 1.8 (0.49)    | 0.3 (-0.51)   | 1.4 (0.61)   | 1.5 (0.04)   | 1.7 (0.16)    | 1.5 (-0.13)  | 0.18              | 1.03         | 12.101496  |            |
| 20             | 30            | Plastic industry  | 0.7 (-)   | 0.2 (-0.69)  | 0.8 (2.82)   | 0.2 (-0.72)   | 0.3 (0.25)    | 0.2 (-0.14)   | 0.7 (1.76)   | 0.4 (-0.4)   | 0.7 (0.78)    | 1.2 (0.66)   | 0.48              | 4.61         | 5.493198   |            |
| 21             | 36            | Specialized facility manufacturing industry   | 2.2 (-)   | 1.7 (0.22)   | 1.7 (-0.0)   | 1.8 (0.01)    | 2.2 (0.22)    | 2.3 (0.05)    | 1.2 (-0.46)  | 1.6 (0.33)   | 1.6 (-0.04)   | 1.1 (-0.27)  | -0.04             | -0.35        | 17.437293  |            |
| 22             | 29            | Rubber production industry  | 0.7 (-)   | 0.7 (0.06)   | 0.7 (-0.1)   | 0.6 (-0.06)   | 0.9 (0.38)    | 0.7 (-0.15)   | 0.7 (-0.01)  | 0.6 (-0.19)  | 0.6 (0.04)    | 0.7 (0.17)   | 0.02              | -0.04        | 7.046440   |            |
| 23             | 41            | Manufacturing industry of instruments and meters, and machinery for culture and office            | 1.1 (-)   | 0.3 (-0.74)  | 0.5 (0.84)   | 0.4 (-0.3)    | 0.3 (-0.25)   | 0.4 (0.39)    | 0.6 (0.29)   | 0.5 (-0.08)  | 0.4 (-0.21)   | 0.6 (0.46)   | 0.07              | 1.14         | 5.130449   |            |
| 24             | 21            | Chemical fiber manufacturing industry   | 0.1 (-)   | 1.4 (25.23)  | 3.3 (-0.05)  | 1.3 (-0.0)    | 0.1 (-0.94)   | 0.1 (0.3)     | 0.1 (0.35)   | 0.1 (-0.34)  | 0.1 (0.18)    | 0.4 (2.91)   | 3.07              | -0.69        | 5.130002   |            |
| 25             | 35            | General-purpose equipment manufacturing industry  | 1.2 (-)   | 0.9 (0.13)   | 0.7 (0.03)   | 0.7 (0.03)    | 0.5 (0.03)    | 0.5 (0.03)    | 0.5 (0.03)   | 0.5 (0.03)   | 0.5 (0.03)    | 0.5 (0.03)   | 0.0               | 0.0          | 5.130002   |            |
| 26             | 43            | Processing of discarded resources, and waste and scrap recovery                                   | 0.1 (-)   | 0.2 (2.95)   | 0.1 (-0.36)  | 0.1 (0.03)    | 0.1 (0.03)    | 0.2 (0.85)    | 0.2 (0.85)   | 0.1 (0.24)   | 0.1 (-0.27)   | 0.2 (3.08)   | 1.17              | -0.00        | 2.362047   |            |
| 27             | 43            | Processing of discarded resources, and waste and scrap recovery                                   | 0.0 (-)   | 0.2 (2.95)   | 0.1 (-0.36)  | 0.1 (0.03)    | 0.1 (0.03)    | 0.1 (0.03)    | 0.1 (0.03)   | 0.1 (0.03)   | 0.1 (0.03)    | 0.1 (0.03)   | 0.08              | 0.53         | 0.916783   |            |
| 28             | 24            | Manufacturing industry for culture, education and sports goods                                    | 0.1 (-)   | 0.1 (0.17)   | 0.1 (0.08)   | 0.1 (0.08)    | 0.1 (-0.21)   | 0.1 (-0.06)   | 0.1 (0.14)   | 0.1 (0.25)   | 0.1 (0.04)    | 0.1 (0.08)   | 0.08              | 0.53         | 0.916783   |            |
| 29             | 42            | Artwork and other manufacturing industries  | 0.1 (-)   | 0.1 (0.37)   | 0.2 (0.54)   | 0.2 (0.28)    | 0.2 (-0.27)   | 0.2 (0.43)    | 0.0 (-0.94)  | 0.0 (-0.77)  | 0.0 (-0.7)    | 0.0 (3.02)   | 0.28              | -0.96        | 1.049996   |            |

The table indicates the total emissions of COD (in 10M tons) by year for each sector. The number in parenthesis represents the year-to-year percentage change. The column *average YtY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998, and the last column, *sum period* is the total emission release into the atmosphere over the period.



Table 1.8 in the appendix displays the emission of wastewater pollution across years and sectors. The yearly changes are disparate between sectors. While some sectors have a monotone growth change (*Foodstuff manufacturing industry*, *Chemical fiber manufacturing industry*), others have large percentage changes (*Printing industry and reproduction of record media*). Almost all the sectors have had a positive growth rate since 1999, slightly different from what we observed with the COD (columns 9 in table 1.3). The growth change between 1998 and 2007 is substantially large and heterogeneous. Most-polluted sectors like *Papermaking and paper product industry* or *Textile industry* have experienced 150 and 210 percent increase in emissions, while less-polluted sectors such as *Plastic industry* or *Wood processing and manufacturing* industries grew by 17% and 13% respectively.

The emission of SO<sub>2</sub> by sectors is comparable to the wastewater and COD (table 1.9 in the appendix). The largest emitter of SO<sub>2</sub> is *Non-metallic minerals product industry*, with 14,950 million tons released from 1998 to 2007. The second-largest polluted sector *Ferrous metal smelting and extrusion* emitted 132% more SO<sub>2</sub> emission in 2007 from 1998 and is closely followed by *Chemical feedstock and chemical manufacturing industry*. Energy-related emissions from the manufacturing of *Non-ferrous smelting and extrusion* grew by 10% from 2006 to 2007, releasing 6830 million tons in 2007.

In table 1.4, we rank the sectors according to their emissions of pollution (COD, wastewater, and SO<sub>2</sub>) in 2007. The *Papermaking and paper product industry* holds first place for both the COD and wastewater emissions and ranks sixth for SO<sub>2</sub> emission. *Chemical feedstock and chemical manufacturing industry* is among the most-polluting industries for each of the three main pollutants (third position for the COD and SO<sub>2</sub> and the second position for wastewater). The *Textile industry* largely contributes to the overall country's emission of pollution, ranking fourth for COD, third for wastewater, and seventh for SO<sub>2</sub>. On the contrary, the most SO<sub>2</sub> emissions polluted sector is *Non-metallic minerals product indus-*

try, although this sector ranks in the middle for the COD and wastewater (12th and 11th). The ranking is homogeneous across pollutants with *Processing of discarded resources, and waste and scrap recovery*, *Manufacturing industry for culture, education and sports goods*, and *Artwork and other manufacturing industries* at the bottom.

**Table 1.4: Rank total emission COD, wastewater, and SO2**

| CIC two-digits 2002-revision | name  | COD | wastewater | SO2 |
|------------------------------|---|-----|------------|-----|
| 0 22                         | Papermaking and paper product industry  | 1   | 1          | 6   |
| 1 13                         | Manufacturing of agricultural and non-staple foodstuff  | 2   | 5          | 8   |
| 2 26                         | Chemical feedstock and chemical manufacturing industry  | 3   | 2          | 3   |
| 3 17                         | Textile industry  | 4   | 3          | 7   |
| 4 15                         | Beverage manufacturing industry   | 5   | 7          | 9   |
| 5 32                         | Ferrous metal smelting and extrusion  | 6   | 4          | 2   |
| 6 27                         | Medicine manufacturing industry   | 7   | 9          | 12  |
| 7 14                         | Foodstuff manufacturing industry  | 8   | 10         | 11  |
| 8 28                         | Chemical fiber manufacturing industry   | 9   | 8          | 10  |
| 9 25                         | Petroleum processing, coking and nuclear fuel manufacture   | 10  | 6          | 5   |
| 10 19                        | Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products          | 11  | 15         | 21  |
| 11 31                        | Non-metallic minerals product industry  | 12  | 11         | 1   |
| 12 33                        | Non-ferrous smelting and extrusion  | 13  | 13         | 4   |
| 13 34                        | Metalwork industry  | 14  | 12         | 14  |
| 14 37                        | Transport and communication facilities manufacturing industry                                     | 15  | 16         | 16  |
| 15 39                        | Electric machinery and equipment manufacturing industry   | 16  | 14         | 20  |
| 16 18                        | Manufacturing industry of textile costumes, shoes, and caps                                       | 17  | 18         | 23  |
| 17 20                        | Wood processing and manufacturing industry of wood, bamboo, rattan, palm, and straw-made articles | 18  | 22         | 15  |
| 18 35                        | General-purpose equipment manufacturing industry  | 19  | 19         | 17  |
| 19 40                        | Manufacturing industry of communication equipment, computers and other electronic equipment       | 20  | 17         | 24  |
| 20 30                        | Plastic industry  | 21  | 24         | 19  |
| 21 36                        | Specialized facility manufacturing industry   | 22  | 20         | 18  |
| 22 29                        | Rubber production industry  | 23  | 21         | 13  |
| 23 41                        | Manufacturing industry of instruments and meters, and machinery for culture and office            | 24  | 23         | 25  |
| 24 21                        | Cabinetmaking industry  | 25  | 27         | 26  |
| 25 16                        | Tobacco industry  | 26  | 25         | 22  |
| 26 23                        | Printing industry and reproduction of record media  | 27  | 26         | 27  |
| 27 43                        | Processing of discarded resources, and waste and scrap recovery                                   | 28  | 29         | 28  |
| 28 24                        | Manufacturing industry for culture, education and sports goods                                    | 29  | 28         | 29  |
| 29 42                        | Artwork and other manufacturing industries  | 30  | 30         | 30  |

The table shows the rank of each industry in the 2007 COD emissions.

## 1.6 Data description by year

In the previous section, we provided statistics about the distribution of pollution emissions across sectors. This section looks at pollution emissions across 30 provinces/municipalities in China. Table 1.5 summarizes the total amount of COD emission with the percentage change over time. Guangxi is the most polluted province, releasing 5,075 million tons of COD into the atmosphere from 1998 to 2007. Guangxi displays an average of 5% increase per year.

Figure 1.10 shows the percentage change of COD for each province between 2000 to 2007. Guangxi has reduced its COD emission in 2007 compared with 2000. Qinghai contributes

**Table 1.5: Yearly change COD emission by province**

| province_en | 1998           | 1999      | 2000          | 2001          | 2002          | 2003          | 2004          | 2005          | 2006          | 2007          | average YtY change | change 98-07 | sum period  |
|-------------|----------------|-----------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|--------------------|--------------|-------------|
| 0           | Guangxi        | 446.1 (-) | 397.7 (-0.11) | 634.4 (0.6)   | 396.7 (-0.37) | 475.5 (0.2)   | 522.1 (0.1)   | 564.6 (0.08)  | 537.1 (-0.05) | 555.8 (0.03)  | 546.1 (-0.02)      | -0.14        | 5075.994973 |
| 1           | Hubei          | 364.7 (-) | 242.7 (-0.33) | 232.7 (-0.04) | 307.7 (0.32)  | 236.4 (-0.23) | 296.6 (0.25)  | 304.9 (0.03)  | 321.1 (0.05)  | 292.3 (-0.09) | 268.9 (-0.08)      | 0.05         | 2867.359137 |
| 2           | Shandong       | 157.6 (-) | 424.5 (1.69)  | 452.1 (0.06)  | 408.9 (-0.1)  | 228.5 (-0.44) | 231.4 (0.01)  | 299.2 (0.29)  | 305.5 (0.02)  | 279.5 (-0.09) | 257.0 (-0.08)      | 0.15         | 3044.292135 |
| 3           | Henan          | 422.0 (-) | 397.2 (-0.06) | 333.6 (-0.16) | 317.4 (-0.05) | 280.9 (-0.11) | 249.3 (-0.11) | 269.4 (0.08)  | 239.2 (-0.11) | 235.0 (-0.02) | 237.9 (0.01)       | -0.06        | 2982.014930 |
| 4           | Zhejiang       | 305.1 (-) | 219.1 (-0.28) | 208.6 (0.23)  | 231.5 (-0.14) | 238.3 (0.03)  | 217.3 (-0.09) | 208.0 (-0.04) | 236.0 (0.13)  | 238.5 (0.01)  | 234.3 (-0.02)      | -0.02        | 2396.649883 |
| 5           | Jiangsu        | 253.6 (-) | 205.8 (-0.19) | 184.4 (-0.1)  | 246.3 (0.34)  | 229.8 (-0.07) | 227.8 (-0.01) | 236.2 (0.04)  | 268.7 (0.14)  | 250.1 (-0.07) | 225.0 (-0.1)       | 0.22         | 2327.708973 |
| 6           | Hunan          | 262.5 (-) | 230.9 (-0.12) | 200.9 (-0.13) | 175.8 (-0.12) | 244.8 (0.39)  | 213.0 (-0.13) | 230.6 (0.08)  | 241.5 (0.05)  | 253.3 (0.05)  | 220.4 (-0.13)      | 0.10         | 2273.614609 |
| 7           | Liaoning       | 0.0 (-)   | 298.4 (-)     | 288.2 (-0.03) | 256.8 (-0.11) | 193.8 (-0.25) | 132.8 (-0.31) | 117.4 (-0.12) | 217.5 (0.85)  | 220.5 (0.01)  | 202.2 (-0.08)      | -            | 1927.556246 |
| 8           | Sichuan        | 271.8 (-) | 209.2 (-0.23) | 246.1 (0.18)  | 450.9 (0.83)  | 366.0 (-0.19) | 371.7 (0.02)  | 313.8 (-0.16) | 253.6 (-0.19) | 192.8 (-0.24) | 187.9 (-0.02)      | -0.00        | 2863.896590 |
| 9           | Shaanxi        | 90.6 (-)  | 79.9 (-0.12)  | 88.3 (0.1)    | 112.3 (0.27)  | 102.7 (-0.09) | 100.5 (-0.02) | 104.8 (0.04)  | 126.0 (0.2)   | 145.1 (0.15)  | 158.1 (0.09)       | 0.07         | 1108.474645 |
| 10          | Guangdong      | 244.2 (-) | 263.6 (0.08)  | 202.7 (-0.23) | 167.1 (-0.18) | 146.8 (-0.12) | 113.3 (-0.23) | 89.4 (-0.21)  | 87.9 (-0.02)  | 81.2 (-0.08)  | 156.1 (0.92)       | -0.01        | 1552.113492 |
| 11          | Xinjiang       | 118.5 (-) | 106.6 (-0.1)  | 71.7 (-0.33)  | 71.3 (-0.01)  | 92.1 (0.29)   | 112.2 (0.22)  | 123.7 (0.1)   | 127.5 (0.03)  | 135.1 (0.06)  | 143.1 (0.07)       | 0.04         | 1103.851116 |
| 12          | Jilin          | 143.7 (-) | 192.4 (0.34)  | 188.8 (-0.02) | 138.6 (-0.27) | 98.8 (-0.29)  | 124.3 (0.26)  | 121.9 (-0.02) | 137.0 (0.12)  | 142.6 (0.04)  | 143.8 (0.01)       | 0.02         | 1431.959952 |
| 13          | Hubei          | 234.6 (-) | 230.3 (-0.02) | 190.1 (-0.17) | 180.7 (-0.05) | 157.1 (-0.13) | 141.7 (-0.1)  | 147.8 (0.04)  | 148.5 (0.0)   | 144.3 (-0.03) | 130.8 (-0.09)      | -0.06        | 1706.011359 |
| 14          | Anhui          | 137.7 (-) | 155.1 (0.13)  | 88.9 (-0.43)  | 103.7 (0.17)  | 94.0 (-0.09)  | 93.3 (-0.01)  | 94.5 (0.01)   | 114.0 (0.21)  | 104.9 (-0.08) | 111.0 (0.06)       | 0.25         | 1097.053931 |
| 15          | Heilongjiang   | 2.5 (-)   | 150.0 (59.43) | 114.6 (-0.24) | 97.8 (-0.15)  | 95.7 (-0.02)  | 91.3 (-0.05)  | 82.3 (-0.1)   | 88.6 (0.08)   | 98.0 (0.11)   | 106.9 (0.09)       | -0.07        | 927.647350  |
| 16          | Shanxi         | 193.8 (-) | 135.4 (-0.3)  | 67.4 (-0.5)   | 115.0 (0.71)  | 107.2 (-0.07) | 109.2 (0.02)  | 113.5 (0.04)  | 127.2 (0.12)  | 124.9 (-0.02) | 106.8 (-0.14)      | 0.58         | 1200.381995 |
| 17          | Inner Mongolia | 121.1 (-) | 110.9 (-0.08) | 118.3 (0.07)  | 114.3 (-0.03) | 106.4 (-0.07) | 112.5 (0.06)  | 103.8 (-0.06) | 116.8 (0.1)   | 103.2 (-0.12) | 96.7 (-0.06)       | -0.02        | 1106.066130 |
| 18          | Ningxia        | 45.9 (-)  | 61.5 (0.34)   | 129.5 (1.1)   | 89.1 (-0.31)  | 75.7 (-0.15)  | 70.2 (-0.07)  | 44.3 (-0.37)  | 89.1 (1.01)   | 95.0 (0.07)   | 96.0 (0.01)        | 0.18         | 796.375533  |
| 19          | Jiangxi        | - (-)     | - (-)         | 72.9 (-)      | 82.8 (0.14)   | 63.2 (-0.24)  | 72.3 (0.14)   | 83.3 (0.15)   | 101.0 (0.21)  | 82.5 (-0.18)  | 86.6 (0.05)        | 0.04         | 644.740930  |
| 20          | Yunnan         | 224.5 (-) | 251.2 (0.12)  | 154.7 (-0.38) | 128.8 (-0.17) | 110.7 (-0.14) | 85.4 (-0.23)  | 78.0 (-0.09)  | 92.6 (0.19)   | 93.9 (0.01)   | 85.1 (-0.09)       | -0.09        | 1304.868501 |
| 21          | Fujian         | 142.8 (-) | 113.7 (-0.2)  | 94.0 (-0.17)  | 81.9 (-0.13)  | 74.1 (-0.1)   | 67.1 (-0.09)  | 75.0 (0.12)   | 86.2 (0.15)   | 80.9 (-0.06)  | 80.7 (-0.0)        | -0.14        | 896.591907  |
| 22          | Chongqing      | 53.4 (-)  | 45.6 (-0.14)  | 46.3 (0.01)   | 32.9 (-0.29)  | 33.5 (0.02)   | 71.4 (1.13)   | 86.8 (0.21)   | 65.8 (-0.24)  | 90.4 (0.37)   | 80.6 (-0.11)       | 0.11         | 606.721625  |
| 23          | Gansu          | 55.6 (-)  | 46.7 (-0.16)  | 48.8 (0.05)   | 42.3 (-0.13)  | 35.9 (-0.15)  | 35.3 (-0.02)  | 33.3 (-0.06)  | 54.2 (0.63)   | 47.6 (-0.12)  | 42.2 (-0.11)       | -0.01        | 441.792189  |
| 24          | Shanghai       | 75.7 (-)  | 64.6 (-0.15)  | 60.2 (-0.07)  | 42.2 (-0.3)   | 38.5 (-0.09)  | 36.4 (-0.05)  | 32.2 (-0.12)  | 30.4 (-0.05)  | 30.7 (0.01)   | 27.0 (-0.12)       | -0.10        | 437.840454  |
| 25          | Tianjin        | - (-)     | - (-)         | 34.0 (-)      | 31.5 (-0.07)  | 29.0 (-0.08)  | 28.2 (-0.03)  | 25.7 (-0.09)  | 45.0 (0.75)   | 26.4 (-0.41)  | 22.9 (-0.13)       | -0.33        | 242.694223  |
| 26          | Qinghai        | 47.7 (-)  | 3.2 (-0.33)   | 3.2 (0.02)    | 2.5 (-0.23)   | 3.0 (0.21)    | 2.6 (-0.15)   | 2.1 (-0.19)   | 34.2 (15.36)  | 22.8 (-0.33)  | 21.9 (-0.04)       | 1.59         | 100.159224  |
| 27          | Guizhou        | 576.7 (-) | 73.3 (-0.87)  | 73.4 (0.0)    | 26.5 (-0.64)  | 23.7 (-0.11)  | 22.1 (-0.07)  | 18.1 (-0.18)  | 17.7 (-0.03)  | 14.7 (-0.17)  | 14.5 (-0.01)       | -0.23        | 860.640413  |
| 28          | Hainan         | 30.9 (-)  | 27.7 (-0.1)   | 23.3 (-0.16)  | 12.7 (-0.46)  | 11.2 (-0.12)  | 11.7 (0.05)   | 10.5 (-0.1)   | 10.8 (0.02)   | 9.7 (-0.1)    | 9.5 (-0.02)        | -0.11        | 157.829511  |
| 29          | Beijing        | - (-)     | 21.2 (-)      | 20.9 (-0.01)  | 12.5 (-0.4)   | 11.6 (-0.08)  | 1.0 (-0.91)   | 7.4 (6.11)    | 7.7 (0.03)    | 8.4 (0.1)     | 4.7 (-0.44)        | 0.55         | 95.450234   |

The table indicates the total emissions of COD (in 10M tons) for each province by year. The number in parenthesis represents the year-to-year percentage change. The column *average YtY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998 and the last column, *sum period* is the total emission over the period released in the atmosphere.

relatively little to the total emissions but emits at the fastest speed (576% between 2000 to 2007). Three out of four municipalities have reduced their emissions of COD over time. Shanghai decreased emissions by 55%, Beijing by 78%, and Tianjin by 33%. Chongqing, however, increased emissions by 77%.

**Figure 1.10: Change in COD emissions from 2000 and 2007**

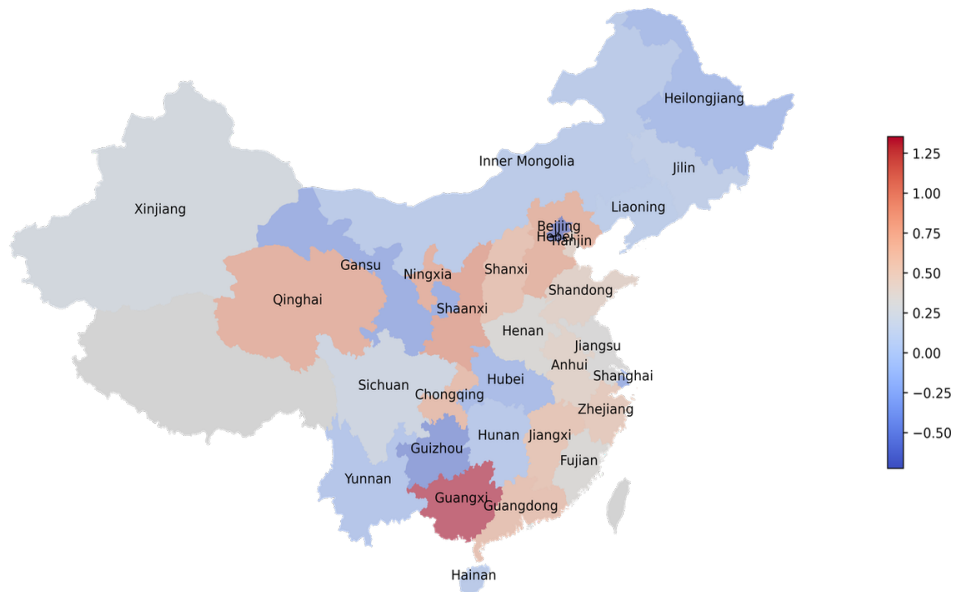


**Note:** The figure map the change in COD emissions (in 10M tons) by province between 2000 and 2007. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

Figure 1.11 below shows the growth rate of wastewater between 2000 and 2007. Overall, the change is less pronounced than COD emissions, with a maximum change attributed to the province of Guangxi (135%) and the lowest change attributed to Beijing with -72%. The northern region has reduced wastewater disposal relatively more than the coastal and southern provinces. Table 1.10 and 1.11 in the appendix provides the province-year changes for wastewater and SO<sub>2</sub>.

Figure 1.12 provides a more in-depth overview of the COD emissions patterns in China's major areas. Following Wu et al. (2017), we split the cities into coastal, southwest, central, northeast, and northwest areas. The Central provinces are Anhui Henan, Hubei, Hunan,

**Figure 1.11: Change in wastewater emissions from 2000 and 2007**



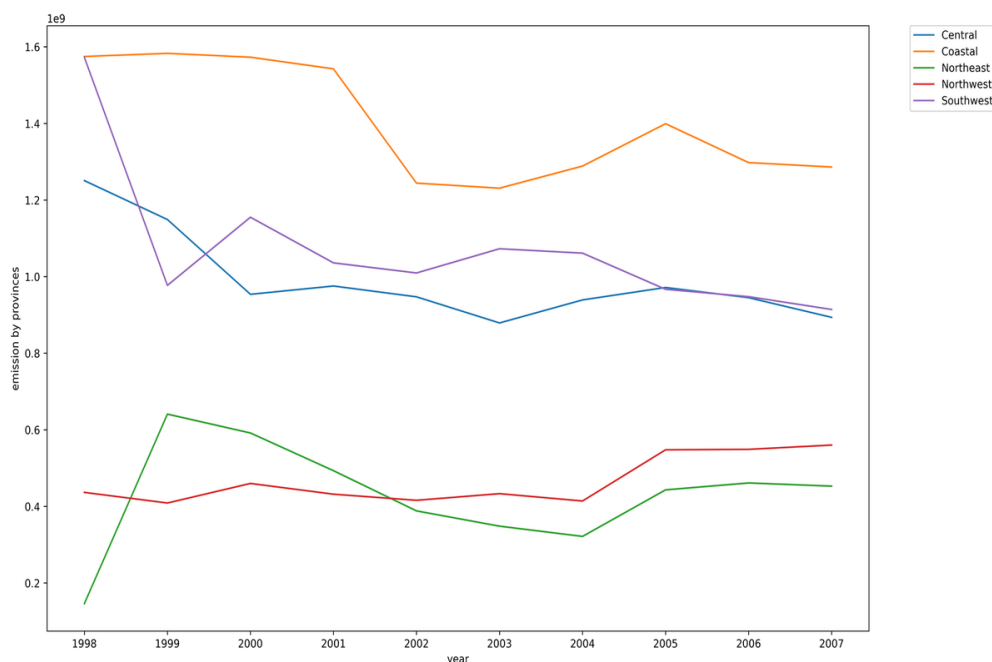
**Note:** The figure map the change in wastewater emissions (in 100M tons) by province between 2000 and 2007. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

Jiangxi, and Shanxi. The Coastal provinces are Beijing, Fujian, Guangdong, Hainan Hebei, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang. The Northeastern provinces are Heilongjiang, Jilin, and Liaoning. Northwest are Gansu, Inner Mongolia, Ningxia, Qinghai, Shaanxi, and Xinjiang. The southwestern parts are Chongqing, Guangxi, Guizhou, Sichuan, Yunnan, and Xizang.

The coastal provinces emit the most COD emissions throughout the period, closely followed by the central and southwest areas. The northwest and east provinces have the lowest emission. This result is not surprising since the manufacturing area is located along the coast and the south.

Figure 1.13 displays the contribution of each major area to the total emissions. The contribution is relatively stable over time except for the Northwest provinces, which increased their emissions proportionally more than the other areas.

**Figure 1.12: COD emissions by cities location**



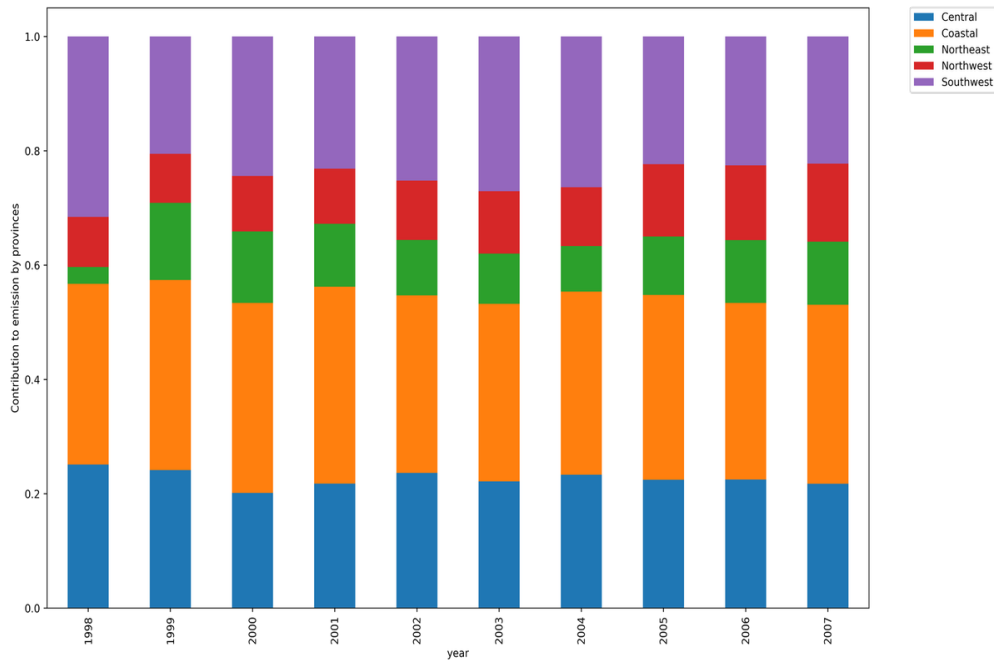
**Note:** COD emissions are stated in 10M tons. Cities are split following Wu et al. (2017). The Central provinces are Anhui Henan, Hubei, Hunan, Jiangxi, and Shanxi. The Coastal provinces are Beijing, Fujian, Guangdong, Hainan Hebei, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang. The Northeastern provinces are Heilongjiang, Jilin, and Liaoning. Northwest are Gansu, Inner Mongolia, Ningxia, Qinghai, Shaanxi, and Xinjiang. The southwestern parts are Chongqing, Guangxi, Guizhou, Sichuan, Yunnan, and Xizang.  
**Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

## 1.7 Data description by sector-province-year

In the previous section, we were interested in seeing the sectorial pollution emission patterns across provinces. In the previous sections, we showed that the emissions across provinces was substantially stable but heterogeneous across sectors and time. In table 1.6 of the current section, we calculate the number of sectors contributing to 75% of the total emission of COD<sup>7</sup> by province for each year. Across all provinces, around eight sectors contribute to 75% of the total emission (five or six if we move the threshold to 80%. In Hebei for instance, the top 8 contributing sectors are *Ferrous metal smelting and extrusion*, *Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products*, *Textile industry*, *Manufacturing*

<sup>7</sup>Tables 1.12 and 1.13 in the appendix provide results for wastewater and SO<sub>2</sub>

**Figure 1.13: Contribution of COD emissions by cities location**



**Note:** COD emissions are stated in 10M tons. Cities are split following Wu et al. (2017). The Central provinces are Anhui Henan, Hubei, Hunan, Jiangxi, and Shanxi. The Coastal provinces are Beijing, Fujian, Guangdong, Hainan Hebei, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang. The Northeastern provinces are Heilongjiang, Jilin, and Liaoning. Northwest are Gansu, Inner Mongolia, Ningxia, Qinghai, Shaanxi, and Xinjiang. The southwestern parts are Chongqing, Guangxi, Guizhou, Sichuan, Yunnan, and Xizang.  
**Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

*of agricultural and non-staple foodstuff, Medicine manufacturing industry, Chemical feedstock and chemical manufacturing industry, and Papermaking and paper product industry. The 75% threshold varies between 63.8 in 1998 to 118.3 in 2005 (number in parenthesis).*

In the appendix (figure 1.15, 1.16, 1.17, 1.18), we plotted the total emission of COD (wastewater and SO<sub>2</sub> are available upon request) by sector-province-year to see the evolution and the concentration of the emissions. We split the sample into four categories based on the GDP per capita of the province. We calculated the GDP per capita of each city and then computed the average per province. We split the provinces into very poor, poor, middle, and rich provinces. Specifically, the poor provinces are Gansu, Jiangxi, Guangxi, Shanxi, Hubei, Hunan, Hunan, while the rich are Fujian, Zhejiang, Jiangsu, Beijing, Tianjin,

**Table 1.6: Contribution of the top polluted sectors to the total COD emission**

| year | province_en    | 1998     | 1999     | 2000     | 2001     | 2002     | 2003     | 2004     | 2005      | 2006      | 2007     |
|------|----------------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|----------|
| 0    | Hebei          | 8 (63.8) | 8 (27.6) | 8 (27.8) | 7 (63.6) | 7 (63.4) | 8 (70.6) | 7 (76.5) | 7 (118.3) | 7 (100.1) | 7 (99.4) |
| 1    | Henan          | 7 (51.3) | 7 (61.1) | 8 (51.2) | 7 (36.1) | 8 (46.0) | 7 (41.1) | 7 (49.0) | 7 (60.1)  | 7 (64.5)  | 7 (73.9) |
| 2    | Shandong       | 8 (35.0) | 8 (53.3) | 8 (58.7) | 8 (73.8) | 8 (53.5) | 7 (67.0) | 7 (68.8) | 7 (70.5)  | 8 (63.2)  | 8 (68.6) |
| 3    | Jiangsu        | 8 (70.1) | 8 (27.8) | 8 (32.0) | 8 (57.2) | 7 (58.4) | 8 (54.5) | 8 (58.9) | 7 (65.8)  | 8 (56.0)  | 8 (49.9) |
| 4    | Anhui          | 7 (30.9) | 7 (41.0) | 7 (31.9) | 7 (31.0) | 7 (27.4) | 7 (23.1) | 7 (25.7) | 7 (27.5)  | 8 (53.0)  | 7 (49.5) |
| 5    | Zhejiang       | 8 (60.2) | 8 (62.7) | 8 (61.0) | 8 (37.1) | 8 (39.2) | 8 (52.8) | 8 (33.9) | 8 (44.6)  | 7 (41.4)  | 7 (48.7) |
| 6    | Sichuan        | 7 (34.0) | 8 (35.0) | 7 (86.9) | 8 (70.2) | 8 (58.3) | 8 (41.2) | 8 (28.4) | 8 (43.2)  | 8 (37.4)  | 8 (48.2) |
| 7    | Liaoning       | - (-)    | 8 (38.2) | 7 (57.4) | 7 (80.5) | 7 (45.5) | 7 (27.8) | 7 (28.5) | 7 (38.6)  | 7 (56.2)  | 7 (47.4) |
| 8    | Guangdong      | 8 (47.4) | 8 (38.8) | 8 (28.1) | 8 (22.9) | 8 (22.9) | 8 (28.0) | 8 (23.9) | 7 (26.3)  | 8 (24.1)  | 8 (46.6) |
| 9    | Hubei          | 8 (62.9) | 7 (46.8) | 7 (60.5) | 7 (56.9) | 7 (52.5) | 8 (41.0) | 7 (55.9) | 7 (58.1)  | 7 (52.2)  | 7 (35.3) |
| 10   | Heilongjiang   | 5 (0.6)  | 8 (34.6) | 8 (32.4) | 7 (32.4) | 7 (26.3) | 7 (28.2) | 7 (29.6) | 7 (29.9)  | 7 (33.8)  | 7 (34.4) |
| 11   | Chongqing      | 7 (14.9) | 8 (9.9)  | 7 (10.9) | 8 (12.0) | 8 (7.6)  | 7 (27.3) | 8 (37.6) | 7 (30.1)  | 7 (29.1)  | 8 (33.3) |
| 12   | Shanxi         | 8 (15.5) | 8 (6.6)  | 8 (6.9)  | 8 (22.7) | 7 (39.8) | 7 (32.9) | 7 (20.1) | 7 (22.4)  | 7 (41.4)  | 7 (32.0) |
| 13   | Guangxi        | 8 (27.6) | 7 (19.8) | 7 (24.9) | 8 (24.2) | 7 (23.6) | 7 (54.2) | 7 (74.3) | 7 (64.8)  | 7 (88.8)  | 7 (29.9) |
| 14   | Hunan          | 7 (50.3) | 8 (34.3) | 8 (23.9) | 8 (31.5) | 7 (42.7) | 7 (41.1) | 7 (32.3) | 7 (38.6)  | 8 (47.4)  | 8 (28.4) |
| 15   | Jilin          | 7 (16.7) | 7 (13.9) | 7 (16.0) | 8 (15.3) | 7 (15.7) | 7 (15.4) | 7 (17.5) | 7 (42.7)  | 7 (38.9)  | 7 (26.4) |
| 16   | Jiangxi        | - (-)    | - (-)    | 7 (15.8) | 6 (12.5) | 7 (12.4) | 7 (12.1) | 7 (13.7) | 7 (22.3)  | 7 (18.6)  | 7 (23.7) |
| 17   | Xinjiang       | 6 (25.7) | 7 (19.8) | 6 (16.1) | 6 (18.3) | 7 (17.3) | 7 (10.5) | 7 (18.1) | 6 (18.1)  | 6 (25.0)  | 6 (22.9) |
| 18   | Fujian         | 8 (28.7) | 8 (20.4) | 8 (19.8) | 8 (14.3) | 8 (15.3) | 8 (15.4) | 8 (13.8) | 8 (31.7)  | 8 (23.4)  | 8 (21.4) |
| 19   | Inner Mongolia | 7 (14.9) | 7 (12.3) | 7 (20.9) | 7 (13.0) | 7 (9.0)  | 7 (28.7) | 7 (20.4) | 7 (43.5)  | 6 (35.7)  | 6 (19.0) |
| 20   | Shaanxi        | 7 (12.4) | 7 (6.0)  | 7 (7.6)  | 7 (8.4)  | 8 (7.2)  | 7 (17.8) | 7 (19.2) | 7 (17.7)  | 7 (11.3)  | 7 (18.5) |
| 21   | Gansu          | 7 (14.6) | 7 (15.2) | 7 (12.4) | 8 (5.1)  | 7 (9.4)  | 7 (13.6) | 8 (11.6) | 7 (7.9)   | 7 (7.8)   | 7 (15.5) |
| 22   | Tianjin        | - (-)    | - (-)    | 7 (7.3)  | 7 (9.6)  | 8 (7.1)  | 8 (9.8)  | 8 (12.6) | 7 (13.7)  | 7 (10.9)  | 7 (9.1)  |
| 23   | Shanghai       | 8 (22.6) | 7 (20.8) | 7 (20.7) | 7 (11.1) | 7 (9.0)  | 8 (8.2)  | 8 (7.4)  | 8 (10.5)  | 8 (13.5)  | 8 (8.0)  |
| 24   | Ningxia        | 6 (2.4)  | 6 (3.2)  | 6 (1.6)  | 6 (1.9)  | 6 (4.3)  | 5 (3.0)  | 5 (3.8)  | 6 (8.6)   | 5 (7.5)   | 6 (7.4)  |
| 25   | Qinghai        | 6 (2.8)  | 5 (1.2)  | 6 (0.8)  | 5 (1.1)  | 5 (1.4)  | 5 (2.0)  | 4 (1.4)  | 5 (18.9)  | 5 (7.9)   | 5 (5.6)  |
| 26   | Yunnan         | 6 (24.9) | 7 (21.7) | 7 (15.5) | 7 (5.9)  | 6 (5.5)  | 6 (18.8) | 6 (13.2) | 6 (3.1)   | 6 (6.6)   | 7 (4.8)  |
| 27   | Guizhou        | 7 (6.3)  | 8 (3.8)  | 7 (3.2)  | 7 (4.3)  | 7 (10.4) | 8 (5.0)  | 7 (4.8)  | 7 (2.3)   | 7 (1.6)   | 7 (1.8)  |
| 28   | Beijing        | - (-)    | 8 (8.9)  | 7 (8.7)  | 7 (5.9)  | 7 (4.4)  | - (-)    | 7 (2.4)  | 7 (2.4)   | 7 (2.6)   | 7 (1.6)  |
| 29   | Hainan         | 6 (1.4)  | 7 (1.1)  | 7 (1.0)  | 6 (0.9)  | 5 (0.6)  | 5 (0.5)  | 5 (0.9)  | 5 (0.3)   | 5 (0.9)   | 5 (0.5)  |

This table shows the sector's contribution to the total COD emission (in 10M tons). In this table, we count the number of sectors accounting for at least 75% of the total COD emissions. The number in parenthesis indicates the 75% threshold.



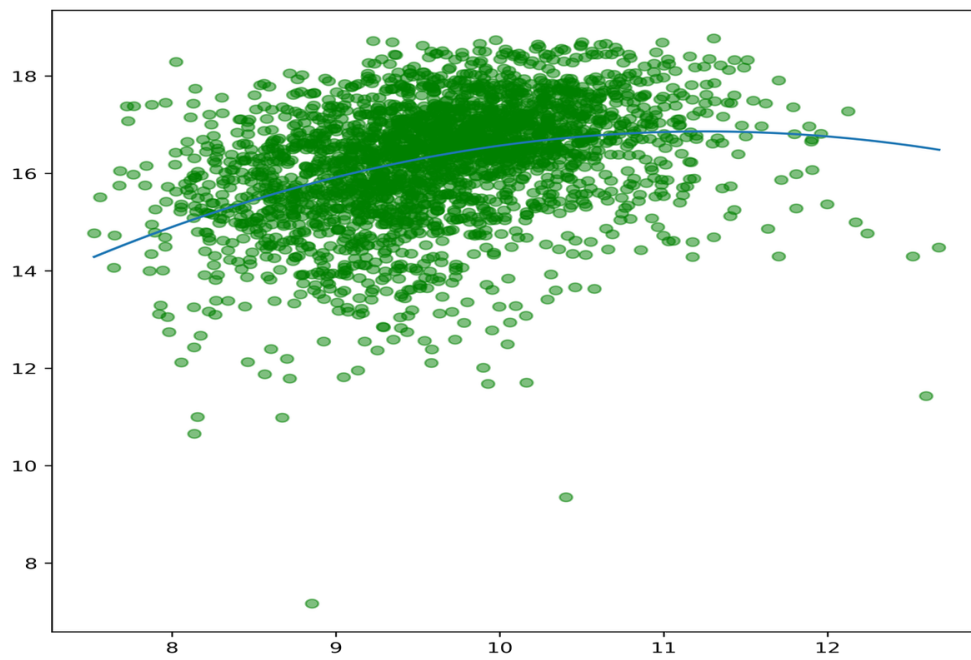
Xinjiang, Shanghai. Yunnan, Inner Mongolia, Liaoning, Hubei, Shandong, Hainan, Guangdong constitute the middle and the remaining are the poorest (Shaanxi, Sichuan, Qinghai, Heilongjiang, Guizhou, Anhui, Ningxia, Jilin). Each figure confirms the concentration of emissions in very few industries and is proportional to the province's wealth.

## 1.8 Environmental Kuznets Curve in China

In the last part of this chapter, we are interested in showing how emissions evolve with income. Economists refer to the relationship between pollution emission and income per capita as the "Environmental Kuznets Curve" (EKC). The EKC was formally attributed to Grossman and Krueger (1995). The EKC is an indicator of how the environment deteriorates with industrialization. The curve shows a positive relationship between income and pollution up to a turning point, whereby pollution decreases with wealth. This decline in emissions can be attributed to new technology, better productivity, and better resource management, improving the environment. A modification of the Kuznets curve explains developing economies' rise and subsequent decline in pollution levels.

In figure 1.14, we plot the log of GDP per capita on the x-axis and the log of SO<sub>2</sub> for each year to visualize the relationship between pollution emissions and income (COD and wastewater in the appendix, figure 1.19 and figure 1.20). Additionally, we calculate the quadratic form between the log of GDP per capita and the log of SO<sub>2</sub> pollution emissions. The turning point gives us a rough idea about the income to reach before reducing pollution emissions in China. According to our very naive model, the turning point is reached with a GDP per capita of 60,000RMB, equivalent to a city like Dongguan. The turning point for the COD is roughly the same (see figure 1.19) while we were unable to identify such a turning point for wastewater (figure 1.20).

**Figure 1.14: SO2 Environmental Kuznets Curve**



**Note:** The graph plots the relationship between the city GDP per capita and SO2 emission (in log). The line represents the quadratic form and shows a turning point at roughly 60.000RMB. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

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## 1.9 Appendix

## Regulations on Industrial Classification: 2 digits per industrial class

| category | class                | industry_class   | CIC02.2003 | name  |
|----------|----------------------|--|------------|---|
| 1        | The Primary Industry | A Farming, forestry, animal husbandry and fishery                          | 01         | Farming   |
| 2        | The Primary Industry | A Farming, forestry, animal husbandry and fishery                          | 02         | Forestry  |
| 3        | The Primary Industry | A Farming, forestry, animal husbandry and fishery                          | 03         | Animal husbandry  |
| 4        | The Primary Industry | A Farming, forestry, animal husbandry and fishery                          | 04         | Fishery   |
| 5        | The Primary Industry | A Farming, forestry, animal husbandry and fishery                          | 05         | Service industry for farming, forestry, animal husbandry and fishery                              |
| 6        | The second industry  | B Mining industry  | 06         | Coal exploitation and washing   |
| 7        | The second industry  | B Mining industry  | 07         | Exploitation of petroleum and natural gas   |
| 8        | The second industry  | B Mining industry  | 08         | Extracting and dressing of ferrous metal mines  |
| 9        | The second industry  | B Mining industry  | 09         | Extracting and dressing of non-ferrous metal ores   |
| 10       | The second industry  | B Mining industry  | 10         | Extracting and dressing of nonmetal ores  |
| 11       | The second industry  | B Mining industry  | 11         | Other mining industries   |
| 12       | The second industry  | C Manufacturing industry   | 13         | Manufacturing of agricultural and non-staple foodstuff  |
| 13       | The second industry  | C Manufacturing industry   | 14         | Foodstuff manufacturing industry  |
| 14       | The second industry  | C Manufacturing industry   | 15         | Beverage manufacturing industry   |
| 15       | The second industry  | C Manufacturing industry   | 16         | Tobacco industry  |
| 16       | The second industry  | C Manufacturing industry   | 17         | Textile industry  |
| 17       | The second industry  | C Manufacturing industry   | 18         | Manufacturing industry of textile costumes, shoes, and caps                                       |
| 18       | The second industry  | C Manufacturing industry   | 19         | Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products          |
| 19       | The second industry  | C Manufacturing industry   | 20         | Wood processing and manufacturing industry of wood, bamboo, rattan, palm, and straw-made articles |
| 20       | The second industry  | C Manufacturing industry   | 21         | Cabinetmaking industry  |
| 21       | The second industry  | C Manufacturing industry   | 22         | Papermaking and paper product industry  |
| 22       | The second industry  | C Manufacturing industry   | 23         | Printing industry and reproduction of record media  |
| 23       | The second industry  | C Manufacturing industry   | 24         | Manufacturing industry for culture, education and sports goods                                    |
| 24       | The second industry  | C Manufacturing industry   | 25         | Petroleum processing, coking and nuclear fuel manufacture   |
| 25       | The second industry  | C Manufacturing industry   | 26         | Chemical feedstock and chemical manufacturing industry  |
| 26       | The second industry  | C Manufacturing industry   | 27         | Medicine manufacturing industry   |
| 27       | The second industry  | C Manufacturing industry   | 28         | Chemical fiber manufacturing industry   |
| 28       | The second industry  | C Manufacturing industry   | 29         | Rubber production industry  |
| 29       | The second industry  | C Manufacturing industry   | 30         | Plastic industry  |
| 30       | The second industry  | C Manufacturing industry   | 31         | Non-metallic minerals product industry  |
| 31       | The second industry  | C Manufacturing industry   | 32         | Ferrous metal smelting and extrusion  |
| 32       | The second industry  | C Manufacturing industry   | 33         | Non-ferrous smelting and extrusion  |
| 33       | The second industry  | C Manufacturing industry   | 34         | Metalwork industry  |
| 34       | The second industry  | C Manufacturing industry   | 35         | General-purpose equipment manufacturing industry  |
| 35       | The second industry  | C Manufacturing industry   | 36         | Specialized facility manufacturing industry   |
| 36       | The second industry  | C Manufacturing industry   | 37         | Transport and communication facilities manufacturing industry                                     |
| 37       | The second industry  | C Manufacturing industry   | 39         | Electric machinery and equipment manufacturing industry   |
| 38       | The second industry  | C Manufacturing industry   | 40         | Manufacturing industry of communication equipment, computers and other electronic equipment       |
| 39       | The second industry  | C Manufacturing industry   | 41         | Manufacturing industry of instruments and meters, and machinery for culture and office            |
| 40       | The second industry  | C Manufacturing industry   | 42         | Artwork and other manufacturing industries  |
| 41       | The second industry  | C Manufacturing industry   | 43         | Processing of discarded resources, and waste and scrap recovery                                   |
| 42       | The second industry  | D Production and supply of electric power, gas and water                   | 44         | Production and supply of electric power and heat power  |
| 43       | The second industry  | D Production and supply of electric power, gas and water                   | 45         | Gas generation and supply   |
| 44       | The second industry  | D Production and supply of electric power, gas and water                   | 46         | Water production and supply   |
| 45       | The second industry  | E Construction industry  | 47         | Building and civil engineer work industry   |
| 46       | The second industry  | E Construction industry  | 48         | Construction and installation industry  |
| 47       | The second industry  | E Construction industry  | 49         | Architectural decoration industry   |
| 48       | The second industry  | E Construction industry  | 50         | Other building industries   |
| 49       | The third industry   | F Traffic, storage and mail business                                       | 51         | Railage industry  |
| 50       | The third industry   | F Traffic, storage and mail business                                       | 52         | Road transport industry   |
| 51       | The third industry   | F Traffic, storage and mail business                                       | 53         | Urban public traffic industry   |
| 52       | The third industry   | F Traffic, storage and mail business                                       | 54         | Marine traffic industry   |
| 53       | The third industry   | F Traffic, storage and mail business                                       | 55         | Air transport industry  |
| 54       | The third industry   | F Traffic, storage and mail business                                       | 56         | Pipage industry   |
| 55       | The third industry   | F Traffic, storage and mail business                                       | 57         | Loading and unloading, portage and other transport service industries                             |
| 56       | The third industry   | F Traffic, storage and mail business                                       | 58         | Storage industry  |
| 57       | The third industry   | F Traffic, storage and mail business                                       | 59         | Mail business   |
| 58       | The third industry   | G Information transfer, computer service and software industry             | 60         | Telecom and other information transfer service industry   |
| 59       | The third industry   | G Information transfer, computer service and software industry             | 61         | Computer service industry   |
| 60       | The third industry   | G Information transfer, computer service and software industry             | 62         | Software industry   |
| 61       | The third industry   | H Wholesale and retail trade   | 63         | Wholesale establishment   |
| 62       | The third industry   | H Wholesale and retail trade   | 65         | Retail trade  |
| 63       | The third industry   | I Accommodation and food industry  | 66         | Lodging industry  |
| 64       | The third industry   | I Accommodation and food industry  | 67         | Food industry   |
| 65       | The third industry   | J Finance industry   | 68         | Banking   |
| 66       | The third industry   | J Finance industry   | 69         | Securities business   |
| 67       | The third industry   | J Finance industry   | 70         | Underwriting  |
| 68       | The third industry   | J Finance industry   | 71         | Other finance operations  |
| 69       | The third industry   | K Realty business  | 72         | Realty business   |
| 70       | The third industry   | L Leasehold and business service industry                                  | 73         | Leasing industry  |
| 71       | The third industry   | L Leasehold and business service industry                                  | 74         | Commerce service industry   |
| 72       | The third industry   | M Scientific research, technical service and geologic examination industry | 75         | Development of researches and tests   |
| 73       | The third industry   | M Scientific research, technical service and geologic examination industry | 76         | Profession skill service industry   |
| 74       | The third industry   | M Scientific research, technical service and geologic examination industry | 77         | Both scientific and technological communications and generalization                               |
| 75       | The third industry   | M Scientific research, technical service and geologic examination industry | 78         | Geologic examination industry   |
| 76       | The third industry   | N Water conservancy, environment and public institution management         | 79         | Water management  |
| 77       | The third industry   | N Water conservancy, environment and public institution management         | 80         | Environmental management  |
| 78       | The third industry   | N Water conservancy, environment and public institution management         | 81         | Public facility management  |
| 79       | The third industry   | O Neighborhood services and other service industry                         | 82         | Neighborhood services industry  |
| 80       | The third industry   | O Neighborhood services and other service industry                         | 83         | Other service industries  |
| 81       | The third industry   | P Education  | 84         | Education   |
| 82       | The third industry   | Q Sanitation, social security and social welfare industry                  | 85         | Sanitation  |
| 83       | The third industry   | Q Sanitation, social security and social welfare industry                  | 86         | Social security industry  |
| 84       | The third industry   | Q Sanitation, social security and social welfare industry                  | 87         | Social welfare industry   |
| 85       | The third industry   | R Cultural, physical and entertainment industry                            | 88         | Journalism industry   |
| 86       | The third industry   | R Cultural, physical and entertainment industry                            | 89         | Radio, TV, film and audiovisual product industry  |
| 87       | The third industry   | R Cultural, physical and entertainment industry                            | 90         | Culture and art industry  |
| 88       | The third industry   | R Cultural, physical and entertainment industry                            | 91         | Physical culture  |
| 89       | The third industry   | R Cultural, physical and entertainment industry                            | 92         | Entertainment industry  |
| 90       | The third industry   | S Public administration and social organization                            | 93         | CCP organ   |
| 91       | The third industry   | S Public administration and social organization                            | 94         | Organs of state   |
| 92       | The third industry   | S Public administration and social organization                            | 95         | The political consultative conference and democratic parties                                      |
| 93       | The third industry   | S Public administration and social organization                            | 96         | Mass organizations, social communities and religion organizations                                 |
| 94       | The third industry   | S Public administration and social organization                            | 97         | Grass roots self-management organizations   |
| 95       | The third industry   | T International organizations  | 98         | International organizations   |

The data comes from the NBS website. The three industries are classified as follows: the first industry refers to agriculture, forestry, stock raising, and fishery. The second industry refers to mining industry, manufacturing, electric undertaking, gas industry, water production and supply industry and building industry.

## Yearly sectoral change of wastewater emission

| CIC02_2003 | name  | 1998      | 1999         | 2000         | 2001          | 2002          | 2003          | 2004         | 2005         | 2006         | 2007         | average      | YY change | change | 98-07       | sum period |
|------------|---|-----------|--------------|--------------|---------------|---------------|---------------|--------------|--------------|--------------|--------------|--------------|-----------|--------|-------------|------------|
| 0          | Papermaking and paper product industry  | 182.8 (-) | 205.6 (0.12) | 210.0 (0.02) | 194.2 (-0.08) | 152.3 (-0.22) | 147.2 (-0.03) | 148.5 (0.01) | 160.1 (0.08) | 156.7 (0.02) | 157.4 (0.03) | 157.4 (0.03) | -0.01     | -0.23  | 1714.904279 |            |
| 1          | Manufacturing of agricultural and non-staple foodstuff  | 75.9 (-)  | 74.0 (-0.02) | 69.8 (-0.06) | 57.0 (-0.18)  | 69.1 (0.21)   | 66.7 (0.03)   | 62.9 (-0.03) | 69.9 (0.11)  | 62.9 (-0.11) | 60.2 (-0.03) | 60.2 (-0.03) | -0.02     | -0.19  | 667.667234  |            |
| 2          | Chemical feedstock and chemical manufacturing industry  | 52.5 (-)  | 48.8 (-0.07) | 47.7 (-0.09) | 45.1 (-0.06)  | 46.2 (0.02)   | 47.0 (0.02)   | 50.2 (0.02)  | 56.8 (0.13)  | 54.2 (-0.05) | 46.8 (-0.14) | 46.8 (-0.14) | -0.01     | -0.04  | 495.326910  |            |
| 3          | Textile industry  | 20.6 (-)  | 20.9 (0.01)  | 22.6 (0.09)  | 22.9 (0.01)   | 24.8 (0.08)   | 24.2 (-0.02)  | 29.9 (0.24)  | 29.8 (0.01)  | 31.9 (0.07)  | 34.5 (0.08)  | 34.5 (0.08)  | 0.06      | 0.05   | 261.997471  |            |
| 4          | Beverage manufacturing industry   | 28.8 (-)  | 30.4 (0.06)  | 29.1 (-0.04) | 36.0 (0.24)   | 23.4 (-0.35)  | 20.8 (-0.11)  | 19.4 (-0.07) | 17.7 (-0.03) | 22.2 (0.18)  | 22.8 (0.03)  | 22.8 (0.03)  | -0.01     | -0.25  | 251.558966  |            |
| 5          | Ferrous metal smelting and extrusion  | 12.9 (-)  | 16.7 (0.3)   | 14.4 (-0.14) | 13.9 (-0.03)  | 14.3 (0.03)   | 13.4 (-0.06)  | 16.0 (0.19)  | 17.4 (0.09)  | 14.8 (-0.15) | 13.4 (-0.1)  | 13.4 (-0.1)  | 0.01      | -0.20  | 147.350597  |            |
| 6          | Medicine manufacturing industry   | 13.9 (-)  | 18.4 (0.32)  | 14.6 (-0.2)  | 14.0 (-0.04)  | 13.8 (-0.02)  | 19.3 (0.4)    | 14.3 (-0.26) | 13.4 (-0.07) | 11.8 (-0.12) | 12.4 (0.06)  | 12.4 (0.06)  | 0.01      | -0.32  | 145.948843  |            |
| 7          | Foodstuff manufacturing industry  | 12.1 (-)  | 15.8 (0.31)  | 14.3 (-0.1)  | 10.1 (-0.29)  | 10.0 (-0.01)  | 9.9 (-0.01)   | 10.6 (0.07)  | 12.0 (0.14)  | 10.9 (-0.09) | 10.8 (-0.01) | 10.8 (-0.01) | 0.00      | -0.22  | 116.451584  |            |
| 8          | Chemical fiber manufacturing industry   | 11.2 (-)  | 12.7 (0.08)  | 5.7 (0.07)   | 5.8 (0.07)    | 10.6 (-0.32)  | 10.6 (-0.01)  | 8.9 (-0.16)  | 10.4 (0.18)  | 11.5 (0.1)   | 9.8 (-0.11)  | 9.8 (-0.11)  | 0.00      | -0.22  | 116.886464  |            |
| 9          | Petroleum processing, coking and nuclear fuel manufacture   | 22.5 (-)  | 7.1 (-0.08)  | 5.7 (0.07)   | 6.7 (-0.11)   | 6.4 (-0.06)   | 4.9 (-0.14)   | 5.8 (0.17)   | 8.4 (0.44)   | 7.4 (-0.11)  | 8.2 (0.11)   | 8.2 (0.11)   | 0.01      | 0.16   | 81.366808   |            |
| 10         | Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products          | 9.6 (-)   | 4.5 (-0.33)  | 7.6 (0.07)   | 6.5 (1.29)    | 6.3 (0.06)    | 5.9 (-0.07)   | 6.8 (0.14)   | 7.6 (0.11)   | 7.1 (-0.06)  | 7.1 (-0.06)  | 7.1 (-0.06)  | 0.01      | 0.37   | 69.352940   |            |
| 11         | Non-metallic mineral product industry   | 38.9 (-)  | 3.3 (-0.32)  | 2.8 (-0.13)  | 6.5 (1.35)    | 2.5 (-0.45)   | 3.4 (0.36)    | 2.8 (-0.16)  | 3.4 (0.21)   | 4.5 (-0.25)  | 4.5 (-0.25)  | 4.5 (-0.25)  | 0.01      | 1.06   | 292.203094  |            |
| 12         | Non-ferrous smelting and extrusion  | 1.5 (-)   | 1.5 (0.03)   | 1.9 (0.26)   | 4.3 (1.35)    | 3.4 (0.36)    | 1.2 (0.11)    | 1.4 (0.18)   | 2.0 (0.4)    | 1.7 (-0.14)  | 2.8 (0.6)    | 2.8 (0.6)    | 0.24      | 2.30   | 13.326230   |            |
| 13         | Transport and communication facilities manufacturing industry                                     | 0.5 (-)   | 0.8 (0.71)   | 0.3 (0.07)   | 0.9 (0.16)    | 3.2 (2.2)     | 3.4 (2.4)     | 0.6 (0.06)   | 0.6 (0.06)   | 0.6 (0.06)   | 0.6 (0.06)   | 0.6 (0.06)   | 0.01      | 0.18   | 10.262300   |            |
| 14         | Transport and communication equipment manufacturing industry                                      | 0.6 (-)   | 0.7 (0.06)   | 1.1 (0.38)   | 1.3 (0.38)    | 1.6 (0.26)    | 1.7 (0.38)    | 1.4 (0.01)   | 1.7 (0.38)   | 1.9 (0.31)   | 2.6 (0.9)    | 2.6 (0.9)    | 0.21      | 2.48   | 13.688630   |            |
| 15         | Manufacturing industry of plastic   | 0.6 (-)   | 0.7 (0.06)   | 0.8 (0.15)   | 0.4 (-0.21)   | 0.5 (0.37)    | 0.7 (0.38)    | 1.4 (0.9)    | 2.1 (0.53)   | 1.7 (-0.12)  | 1.8 (0.04)   | 1.8 (0.04)   | 0.32      | 2.83   | 10.239483   |            |
| 16         | Wood processing and manufacturing industry of wood, bamboo, rattan, palm, and straw-made articles | 3.4 (-)   | 3.8 (0.11)   | 3.7 (0.12)   | 1.9 (-0.43)   | 2.1 (0.1)     | 2.5 (0.23)    | 3.4 (0.34)   | 2.8 (-0.18)  | 2.2 (-0.22)  | 1.6 (-0.23)  | 1.6 (-0.23)  | -0.05     | -0.57  | 27.024075   |            |
| 17         | General-purpose equipment manufacturing industry  | 1.2 (-)   | 1.5 (0.23)   | 1.6 (0.13)   | 1.6 (0.13)    | 1.6 (-0.03)   | 1.3 (-0.17)   | 1.3 (0.02)   | 1.7 (0.36)   | 2.4 (0.36)   | 1.5 (-0.13)  | 1.5 (-0.13)  | 0.06      | 0.10   | 15.842729   |            |
| 18         | Plastic industry  | 0.5 (-)   | 0.7 (0.4)    | 0.8 (0.08)   | 1.2 (0.5)     | 1.8 (0.49)    | 0.9 (-0.51)   | 1.4 (0.61)   | 1.5 (0.04)   | 1.7 (0.16)   | 1.5 (-0.13)  | 1.5 (-0.13)  | 0.18      | 1.03   | 12.101496   |            |
| 19         | Manufacturing industry of communication equipment, computers and other electronic equipment       | 0.7 (-)   | 0.2 (-0.69)  | 0.8 (2.82)   | 0.2 (-0.72)   | 0.3 (0.25)    | 0.2 (-0.14)   | 0.7 (1.70)   | 0.4 (-0.4)   | 0.7 (0.78)   | 1.2 (0.66)   | 1.2 (0.66)   | 0.48      | 4.61   | 5.436198    |            |
| 20         | Specialized facility manufacturing industry   | 2.2 (-)   | 1.7 (-0.22)  | 1.7 (-0.0)   | 1.8 (0.01)    | 2.2 (0.22)    | 2.3 (0.15)    | 1.2 (-0.46)  | 1.6 (-0.19)  | 1.6 (-0.04)  | 1.1 (-0.27)  | 1.1 (-0.27)  | -0.04     | -0.35  | 17.437293   |            |
| 21         | Rubber production industry  | 0.7 (-)   | 0.7 (0.06)   | 0.7 (-0.1)   | 0.6 (-0.06)   | 0.9 (0.38)    | 0.7 (-0.15)   | 0.7 (-0.15)  | 0.6 (-0.01)  | 0.6 (0.04)   | 0.6 (0.04)   | 0.6 (0.04)   | 0.02      | -0.04  | 7.046440    |            |
| 22         | Manufacturing industry of instruments and meters, and machinery for culture and office            | 1.1 (-)   | 0.3 (-0.74)  | 0.5 (0.84)   | 0.4 (-0.3)    | 0.3 (-0.25)   | 0.4 (-0.59)   | 0.6 (0.29)   | 0.5 (-0.08)  | 0.4 (-0.21)  | 0.6 (0.46)   | 0.6 (0.46)   | 0.07      | 1.14   | 5.134049    |            |
| 23         | Cabinetmaking industry  | 0.1 (-)   | 1.4 (25.23)  | 1.3 (-0.05)  | 1.3 (-0.05)   | 0.1 (-0.94)   | 0.1 (0.3)     | 0.1 (0.35)   | 0.1 (-0.34)  | 0.1 (2.91)   | 0.4 (2.91)   | 0.4 (2.91)   | 3.07      | -0.69  | 5.150002    |            |
| 24         | Printing industry   | 1.2 (-)   | 1.0 (-0.13)  | 0.8 (-0.24)  | 0.7 (-0.11)   | 0.7 (-0.03)   | 0.9 (0.35)    | 0.6 (-0.4)   | 0.5 (-0.13)  | 0.4 (-0.14)  | 0.4 (-0.06)  | 0.4 (-0.06)  | -0.10     | -0.62  | 7.189213    |            |
| 25         | Tobacco industry  | 0.1 (-)   | 0.2 (1.09)   | 0.2 (0.26)   | 0.2 (0.02)    | 0.2 (-0.31)   | 0.2 (0.29)    | 0.2 (0.01)   | 0.5 (1.22)   | 0.2 (-0.67)  | 0.2 (0.38)   | 0.2 (0.38)   | 0.25      | 0.16   | 2.269047    |            |
| 26         | Processing of discarded resources, and waste and scrap recovery                                   | 0.0 (-)   | 0.2 (2.95)   | 0.1 (-0.58)  | 0.1 (-0.26)   | 0.0 (-0.93)   | 0.0 (2.85)    | 0.0 (-0.26)  | 0.1 (3.94)   | 0.0 (-0.2)   | 0.2 (3.05)   | 0.2 (3.05)   | 1.17      | -0.00  | 0.725252    |            |
| 27         | Manufacturing industry for culture, education and sports goods                                    | 0.1 (-)   | 0.1 (0.17)   | 0.1 (0.08)   | 0.1 (0.19)    | 0.1 (-0.21)   | 0.1 (-0.06)   | 0.1 (0.14)   | 0.1 (0.25)   | 0.1 (0.04)   | 0.1 (0.08)   | 0.1 (0.08)   | 0.08      | 0.53   | 0.916783    |            |
| 28         | Manufacturing industry for culture, education and sports goods                                    | 0.1 (-)   | 0.1 (0.17)   | 0.1 (0.08)   | 0.1 (0.19)    | 0.1 (-0.21)   | 0.1 (-0.06)   | 0.1 (0.14)   | 0.1 (0.25)   | 0.1 (0.04)   | 0.1 (0.08)   | 0.1 (0.08)   | 0.08      | 0.53   | 0.916783    |            |
| 29         | Artwork and other manufacturing industries  | 0.1 (-)   | 0.1 (0.37)   | 0.2 (0.54)   | 0.2 (0.28)    | 0.2 (-0.27)   | 0.2 (0.43)    | 0.0 (-0.94)  | 0.0 (-0.77)  | 0.0 (-0.77)  | 0.0 (3.62)   | 0.0 (3.62)   | 0.28      | -0.96  | 1.049996    |            |

The table indicates each sector's total wastewater emissions (in 100M tons) by year. The number in parenthesis represents the year-to-year percentage change. The column *average YY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998 and the last column, *sum period* is the total emission over the period released in the atmosphere.

## Yearly sectoral change of SO2 emission

| CIC02_2003 | name  | 1998      | 1999         | 2000         | 2001          | 2002          | 2003          | 2004         | 2005         | 2006         | 2007         | average YTY change | change 98-07 | sum period  |
|------------|---|-----------|--------------|--------------|---------------|---------------|---------------|--------------|--------------|--------------|--------------|--------------------|--------------|-------------|
| 0          | Papermaking and paper product industry  | 182.8 (-) | 205.6 (0.12) | 210.0 (0.02) | 194.2 (-0.08) | 152.3 (-0.22) | 147.2 (-0.03) | 148.5 (0.01) | 160.1 (0.08) | 156.7 (0.02) | 157.4 (0.0)  | -0.01              | -0.23        | 1714.904279 |
| 1          | Manufacturing of agricultural and non-staple foodstuff  | 75.9 (-)  | 74.0 (-0.02) | 69.8 (-0.06) | 57.0 (-0.18)  | 69.1 (0.21)   | 66.7 (-0.03)  | 62.9 (-0.03) | 69.9 (0.11)  | 62.9 (-0.11) | 60.2 (-0.03) | -0.02              | -0.19        | 667.667234  |
| 2          | Chemical feedstock and chemical manufacturing industry  | 52.5 (-)  | 48.8 (-0.07) | 47.7 (-0.02) | 45.1 (-0.06)  | 46.2 (0.02)   | 47.0 (0.02)   | 50.2 (0.02)  | 56.8 (0.13)  | 54.2 (-0.05) | 46.8 (-0.14) | -0.01              | -0.04        | 495.326910  |
| 3          | Textile industry  | 20.6 (-)  | 20.9 (0.01)  | 22.6 (0.09)  | 22.9 (0.01)   | 24.8 (0.08)   | 24.2 (-0.02)  | 29.9 (0.24)  | 29.8 (0.01)  | 31.9 (0.07)  | 34.5 (0.08)  | 0.06               | 0.05         | 261.997471  |
| 4          | Beverage manufacturing industry   | 28.8 (-)  | 30.4 (0.06)  | 29.1 (-0.04) | 36.0 (0.24)   | 23.4 (-0.35)  | 20.8 (-0.11)  | 19.4 (-0.07) | 18.7 (-0.03) | 22.2 (0.18)  | 22.8 (0.03)  | -0.01              | -0.25        | 251.558966  |
| 5          | Non-metallic mineral products and other non-metallic mineral products industry                    | 12.9 (-)  | 16.7 (0.3)   | 14.4 (-0.14) | 13.9 (-0.03)  | 14.3 (0.03)   | 13.4 (-0.06)  | 16.0 (0.19)  | 17.4 (0.09)  | 14.8 (-0.11) | 13.4 (-0.1)  | 0.01               | -0.20        | 147.359697  |
| 6          | Medicine manufacturing industry   | 13.9 (-)  | 18.4 (0.32)  | 14.6 (-0.2)  | 14.0 (-0.04)  | 13.8 (-0.02)  | 19.3 (0.4)    | 14.3 (-0.26) | 13.4 (-0.07) | 11.8 (-0.12) | 12.4 (0.06)  | 0.01               | -0.32        | 145.948843  |
| 7          | Foodstuff manufacturing industry  | 12.1 (-)  | 15.8 (0.31)  | 14.3 (-0.2)  | 10.1 (-0.29)  | 10.0 (-0.01)  | 9.9 (-0.01)   | 10.6 (0.07)  | 12.0 (0.14)  | 10.9 (-0.09) | 10.8 (-0.01) | 0.00               | -0.22        | 116.451584  |
| 8          | Chemical fiber manufacturing industry   | 11.2 (-)  | 12.7 (0.13)  | 15.6 (0.24)  | 15.6 (0.0)    | 10.6 (-0.32)  | 10.6 (-0.0)   | 8.9 (-0.16)  | 10.4 (0.18)  | 11.5 (0.1)   | 9.8 (-0.14)  | 0.00               | -0.22        | 116.886464  |
| 9          | Petroleum processing, coking and nuclear fuel manufacture   | 22.5 (-)  | 7.1 (-0.08)  | 5.7 (0.07)   | 5.8 (0.07)    | 5.7 (-0.02)   | 4.9 (-0.14)   | 5.8 (0.17)   | 8.4 (0.44)   | 7.4 (-0.11)  | 8.2 (0.11)   | -0.04              | 0.16         | 81.366808   |
| 10         | Manufacturing industry of leather, fur, feather (cloth with soft nap) and their products          | 9.6 (-)   | 4.5 (-0.33)  | 7.6 (0.67)   | 6.7 (0.11)    | 6.4 (-0.06)   | 5.9 (-0.07)   | 6.8 (0.14)   | 7.6 (0.11)   | 7.1 (-0.06)  | 7.1 (-0.01)  | 0.01               | 0.36         | 69.352940   |
| 11         | Manufacturing industry of textile, garment and other textile                                      | 38.9 (-)  | 3.3 (-0.32)  | 2.8 (-0.13)  | 6.5 (1.29)    | 2.5 (-0.45)   | 3.4 (0.36)    | 2.8 (-0.16)  | 3.4 (0.21)   | 4.5 (-0.25)  | 3.1 (-0.3)   | 0.01               | 0.37         | 82.005284   |
| 12         | Non-ferrous smelting and extrusion  | 1.5 (-)   | 1.5 (0.03)   | 1.9 (0.26)   | 4.3 (1.35)    | 2.5 (-0.45)   | 3.4 (0.36)    | 2.8 (-0.16)  | 3.4 (0.21)   | 4.5 (-0.25)  | 3.1 (-0.3)   | 0.01               | 0.37         | 82.005284   |
| 13         | Metallurgy and metal manufacturing industry   | 1.5 (-)   | 0.8 (0.71)   | 0.3 (-0.07)  | 0.9 (0.16)    | 2.2 (0.22)    | 1.2 (0.11)    | 1.4 (0.18)   | 2.0 (0.4)    | 1.7 (-0.14)  | 2.8 (0.6)    | 0.24               | 2.30         | 13.329350   |
| 14         | Transport and communication facilities manufacturing industry                                     | 2.5 (-)   | 4.1 (0.6)    | 4.1 (0.0)    | 2.3 (-0.3)    | 3.6 (0.26)    | 3.6 (0.0)     | 3.6 (0.0)    | 4.1 (0.4)    | 3.6 (0.0)    | 3.6 (0.0)    | 0.00               | 1.06         | 29.220304   |
| 15         | Transport and communication equipment manufacturing industry                                      | 0.5 (-)   | 0.7 (0.86)   | 1.2 (0.8)    | 1.3 (0.72)    | 1.6 (0.26)    | 1.7 (0.8)     | 1.4 (0.9)    | 1.7 (0.8)    | 1.9 (0.17)   | 2.6 (0.9)    | 0.21               | 2.08         | 13.682630   |
| 16         | Manufacturing industry of plastic, rubber, glass, and other non-metallic mineral products         | 0.3 (-)   | 0.5 (0.86)   | 0.8 (0.15)   | 0.4 (-0.21)   | 0.5 (0.37)    | 0.7 (0.38)    | 1.4 (0.9)    | 2.1 (0.6)    | 1.7 (-0.17)  | 1.8 (0.04)   | 0.32               | 2.48         | 10.239483   |
| 17         | Wood processing and manufacturing industry of wood, bamboo, rattan, palm, and straw-made articles | 3.4 (-)   | 3.8 (0.11)   | 3.7 (-0.12)  | 1.9 (-0.43)   | 2.1 (0.1)     | 2.5 (0.23)    | 3.4 (0.34)   | 2.8 (-0.18)  | 2.2 (-0.22)  | 1.6 (-0.23)  | -0.05              | -0.57        | 27.024075   |
| 18         | General-purpose equipment manufacturing industry  | 1.2 (-)   | 1.5 (0.23)   | 1.6 (0.13)   | 1.6 (0.0)     | 1.6 (-0.03)   | 1.3 (-0.17)   | 1.3 (0.02)   | 1.7 (0.36)   | 2.4 (0.36)   | 1.6 (-0.33)  | 0.06               | 0.10         | 15.842729   |
| 19         | Plastic industry  | 0.5 (-)   | 0.7 (0.4)    | 0.8 (0.08)   | 1.2 (0.5)     | 1.8 (0.49)    | 0.9 (-0.51)   | 1.4 (0.61)   | 1.5 (0.04)   | 1.7 (0.16)   | 1.5 (-0.13)  | 0.18               | 1.03         | 12.101496   |
| 20         | Specialized facility manufacturing industry   | 0.7 (-)   | 0.2 (-0.69)  | 0.8 (2.82)   | 0.2 (-0.72)   | 0.3 (0.25)    | 0.2 (-0.14)   | 0.7 (1.70)   | 0.4 (-0.4)   | 0.7 (0.78)   | 1.2 (0.66)   | 0.48               | 4.61         | 5.436198    |
| 21         | Rubber production industry  | 2.2 (-)   | 1.7 (-0.22)  | 1.7 (-0.0)   | 1.8 (0.01)    | 2.2 (0.22)    | 2.3 (0.05)    | 1.2 (-0.46)  | 1.6 (-0.33)  | 1.6 (-0.04)  | 1.1 (-0.27)  | -0.04              | -0.35        | 17.437293   |
| 22         | Manufacturing industry of instruments and meters, and machinery for culture and office            | 0.7 (-)   | 0.7 (0.06)   | 0.7 (-0.1)   | 0.6 (-0.06)   | 0.9 (0.38)    | 0.7 (-0.15)   | 0.7 (-0.15)  | 0.6 (-0.19)  | 0.6 (0.04)   | 0.7 (0.17)   | 0.02               | -0.04        | 7.046440    |
| 23         | Manufacturing industry of instruments and meters, and machinery for culture and office            | 1.1 (-)   | 0.3 (-0.74)  | 0.5 (0.84)   | 0.4 (-0.3)    | 0.3 (-0.25)   | 0.4 (-0.59)   | 0.6 (0.29)   | 0.5 (-0.08)  | 0.4 (-0.21)  | 0.6 (0.46)   | 0.07               | 1.14         | 5.134049    |
| 24         | Cabinetmaking industry  | 0.1 (-)   | 1.4 (25.23)  | 1.3 (-0.05)  | 1.3 (-0.0)    | 0.1 (-0.94)   | 0.1 (0.3)     | 0.1 (0.35)   | 0.1 (-0.34)  | 0.1 (0.18)   | 0.4 (2.91)   | 3.07               | -0.69        | 5.150002    |
| 25         | Tobacco industry  | 1.2 (-)   | 1.0 (-0.13)  | 0.8 (-0.24)  | 0.7 (-0.11)   | 0.7 (-0.03)   | 0.9 (0.35)    | 0.6 (-0.4)   | 0.5 (-0.13)  | 0.4 (-0.14)  | 0.4 (-0.06)  | -0.10              | -0.62        | 7.189213    |
| 26         | Printing industry and reproduction of record media  | 0.1 (-)   | 0.2 (1.08)   | 0.2 (0.26)   | 0.2 (0.02)    | 0.2 (-0.31)   | 0.2 (0.29)    | 0.2 (0.01)   | 0.5 (1.22)   | 0.2 (-0.67)  | 0.2 (0.38)   | 0.25               | 0.16         | 2.269047    |
| 27         | Processing of discarded resources, and waste and scrap recovery                                   | 0.0 (-)   | 0.2 (2.95)   | 0.1 (-0.58)  | 0.1 (-0.26)   | 0.0 (-0.93)   | 0.0 (2.85)    | 0.0 (-0.26)  | 0.1 (3.94)   | 0.0 (-0.2)   | 0.2 (3.05)   | 1.17               | -0.00        | 0.725252    |
| 28         | Manufacturing industry for culture, education and sports goods                                    | 0.1 (-)   | 0.1 (0.17)   | 0.1 (0.08)   | 0.1 (0.19)    | 0.1 (-0.21)   | 0.1 (-0.06)   | 0.1 (0.14)   | 0.1 (0.25)   | 0.1 (0.04)   | 0.1 (0.08)   | 0.08               | 0.53         | 0.916783    |
| 29         | Artwork and other manufacturing industries  | 0.1 (-)   | 0.1 (0.37)   | 0.2 (0.54)   | 0.2 (0.28)    | 0.2 (-0.27)   | 0.2 (0.43)    | 0.0 (-0.94)  | 0.0 (-0.77)  | 0.0 (-0.7)   | 0.0 (3.62)   | 0.28               | -0.96        | 1.049996    |

The table indicates each sector's total SO2 emissions (in 10M tons) by year. The number in parenthesis represents the year-to-year percentage change. The column *average YTY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998 and the last column, *sum period* is the total emission over the period released in the atmosphere.

### Yearly change wastewater emission by province

| province.cn       | 1998       | 1999          | 2000          | 2001          | 2002           | 2003           | 2004           | 2005          | 2006          | average YtY change | change 98-07 | sum period   |
|-------------------|------------|---------------|---------------|---------------|----------------|----------------|----------------|---------------|---------------|--------------------|--------------|--------------|
| 0 Jiangsu         | 1401.2 (-) | 1479.5 (0.06) | 1609.9 (0.09) | 1969.6 (0.22) | 1844.0 (-0.06) | 1798.7 (-0.02) | 1988.9 (0.11)  | 2237.0 (0.12) | 2265.2 (0.01) | 2122.5 (-0.06)     | 0.05         | 18716.589126 |
| 1 Zhejiang        | 674.5 (-)  | 713.1 (0.06)  | 1080.1 (0.51) | 1313.4 (0.22) | 1372.8 (0.05)  | 1336.8 (-0.03) | 1319.2 (-0.01) | 1546.1 (0.17) | 1669.9 (0.08) | 1710.4 (0.02)      | 0.12         | 12736.300331 |
| 2 Guangxi         | 629.5 (-)  | 657.4 (0.04)  | 674.3 (0.03)  | 678.9 (0.01)  | 759.2 (0.12)   | 964.6 (0.27)   | 963.1 (-0.0)   | 1096.6 (0.14) | 1956.5 (0.78) | 1587.2 (-0.19)     | 0.13         | 9967.348819  |
| 3 Guangdong       | 836.5 (-)  | 850.1 (-0.01) | 884.7 (0.04)  | 844.1 (-0.05) | 901.6 (0.07)   | 950.6 (0.05)   | 911.2 (-0.04)  | 926.7 (0.02)  | 964.4 (0.04)  | 1494.9 (-0.35)     | 0.08         | 9584.882877  |
| 4 Shandong        | 2224.4 (-) | 810.0 (2.64)  | 887.9 (0.1)   | 859.2 (-0.03) | 799.2 (-0.07)  | 896.0 (0.12)   | 999.4 (0.12)   | 1116.6 (0.12) | 1160.7 (0.04) | 1306.2 (0.13)      | 0.35         | 9057.636115  |
| 5 Henan           | 614.6 (-)  | 677.4 (0.1)   | 752.1 (0.11)  | 774.7 (0.03)  | 784.5 (0.01)   | 769.5 (-0.02)  | 836.9 (0.09)   | 820.6 (-0.02) | 946.2 (0.15)  | 1012.0 (0.07)      | 0.06         | 7988.505616  |
| 6 Hebei           | 621.6 (-)  | 538.3 (-0.13) | 536.4 (-0.0)  | 658.4 (0.23)  | 713.0 (0.08)   | 759.4 (0.07)   | 917.7 (0.21)   | 911.1 (-0.01) | 1020.9 (0.12) | 982.7 (-0.04)      | 0.06         | 7659.615308  |
| 7 Sichuan         | 585.0 (-)  | 564.3 (-0.04) | 683.4 (0.21)  | 825.2 (0.21)  | 826.8 (0.0)    | 810.1 (-0.02)  | 814.2 (0.01)   | 928.9 (0.14)  | 824.1 (-0.11) | 800.3 (-0.03)      | 0.04         | 7662.160313  |
| 8 Liaoning        | 0.0 (-)    | 888.9 (-)     | 787.8 (-0.11) | 716.7 (-0.09) | 738.6 (0.03)   | 670.4 (-0.09)  | 771.2 (0.15)   | 806.8 (0.16)  | 799.8 (-0.11) | 773.6 (-0.03)      | -            | 7043.647707  |
| 9 Hubei           | 1046.4 (-) | 912.0 (-0.13) | 946.2 (0.04)  | 789.8 (-0.17) | 800.7 (0.01)   | 788.3 (-0.02)  | 781.8 (-0.01)  | 693.7 (-0.11) | 704.5 (0.02)  | 717.3 (0.02)       | -0.04        | 8180.867679  |
| 10 Hunan          | 1018.7 (-) | 900.1 (-0.12) | 757.3 (-0.16) | 683.8 (-0.1)  | 744.3 (0.09)   | 729.6 (-0.02)  | 708.1 (-0.03)  | 757.8 (0.07)  | 712.0 (-0.06) | 699.6 (-0.02)      | -0.04        | 7711.448573  |
| 11 Fujian         | 437.4 (-)  | 454.7 (0.04)  | 477.1 (0.05)  | 427.2 (-0.1)  | 456.5 (0.07)   | 469.9 (0.03)   | 513.2 (0.09)   | 581.5 (0.13)  | 600.9 (0.03)  | 641.6 (0.07)       | 0.05         | 5060.058867  |
| 12 Anhui          | 329.5 (-)  | 458.7 (0.39)  | 371.6 (-0.19) | 432.4 (0.16)  | 424.5 (-0.02)  | 426.6 (0.01)   | 436.6 (0.02)   | 450.5 (0.03)  | 472.0 (0.05)  | 541.7 (0.15)       | 0.07         | 4344.041121  |
| 13 Jiangxi        | - (-)      | - (-)         | 288.8 (-)     | 249.6 (-0.14) | 275.7 (0.1)    | 290.8 (0.06)   | 309.6 (0.06)   | 356.1 (0.15)  | 417.8 (0.17)  | 474.6 (0.14)       | 0.08         | 2663.068973  |
| 14 Chongqing      | 237.2 (-)  | 202.5 (-0.15) | 271.8 (0.34)  | 248.6 (-0.09) | 243.0 (-0.02)  | 376.8 (0.35)   | 538.0 (0.43)   | 334.6 (-0.38) | 565.6 (0.69)  | 474.4 (-0.16)      | 0.14         | 3492.549972  |
| 15 Shanghai       | 758.7 (-)  | 699.5 (-0.08) | 640.6 (-0.08) | 550.9 (-0.14) | 520.0 (-0.06)  | 504.8 (-0.03)  | 490.3 (-0.03)  | 427.3 (-0.13) | 401.0 (-0.06) | 399.2 (-0.0)       | -0.07        | 5392.203908  |
| 16 Shaanxi        | 196.5 (-)  | 206.3 (0.05)  | 194.6 (-0.06) | 209.3 (0.08)  | 208.5 (-0.0)   | 242.3 (0.16)   | 280.1 (0.16)   | 315.1 (0.12)  | 308.9 (-0.02) | 377.2 (0.22)       | 0.08         | 2538.797814  |
| 17 Jilin          | 308.8 (-)  | 283.5 (-0.08) | 273.7 (-0.03) | 271.5 (-0.01) | 249.5 (-0.08)  | 245.2 (-0.02)  | 257.0 (0.05)   | 326.0 (0.27)  | 314.5 (-0.04) | 275.9 (-0.12)      | -0.01        | 2805.507691  |
| 18 Shanxi         | 281.4 (-)  | 180.0 (-0.36) | 160.9 (-0.11) | 163.3 (0.02)  | 151.9 (-0.07)  | 143.4 (-0.06)  | 179.9 (0.25)   | 165.1 (-0.08) | 284.4 (0.72)  | 270.0 (-0.05)      | 0.03         | 1980.346198  |
| 19 Yunnan         | 342.1 (-)  | 309.6 (-0.09) | 301.3 (-0.03) | 273.4 (-0.09) | 288.8 (0.06)   | 294.9 (0.02)   | 326.1 (0.11)   | 279.1 (-0.14) | 260.8 (-0.07) | 264.1 (0.01)       | -0.03        | 2940.181203  |
| 20 Heilongjiang   | 7.8 (-)    | 301.5 (37.68) | 327.4 (0.09)  | 327.2 (-0.0)  | 325.3 (-0.01)  | 321.9 (-0.01)  | 252.1 (-0.22)  | 230.3 (-0.09) | 234.0 (0.02)  | 246.1 (0.05)       | 4.17         | 2573.576095  |
| 21 Ningxia        | 71.8 (-)   | 77.9 (0.08)   | 96.4 (0.24)   | 88.8 (-0.08)  | 98.5 (0.11)    | 90.6 (-0.08)   | 80.6 (-0.11)   | 171.0 (1.12)  | 156.1 (-0.09) | 178.6 (0.14)       | 0.15         | 1110.173858  |
| 22 Tianjin        | - (-)      | - (-)         | 110.5 (-)     | 145.3 (0.31)  | 147.3 (0.01)   | 140.3 (-0.05)  | 146.7 (0.05)   | 217.3 (0.48)  | 165.8 (-0.24) | 160.9 (-0.03)      | 0.08         | 1234.014987  |
| 23 Inner Mongolia | 148.8 (-)  | 141.8 (-0.05) | 148.0 (0.04)  | 143.6 (-0.03) | 146.3 (0.02)   | 153.9 (0.05)   | 135.1 (-0.12)  | 146.3 (0.08)  | 148.6 (0.02)  | 141.8 (-0.05)      | -0.00        | 1454.239239  |
| 24 Xinjiang       | 111.6 (-)  | 117.0 (0.05)  | 110.0 (-0.06) | 101.6 (-0.08) | 107.6 (0.06)   | 108.9 (0.01)   | 115.0 (0.06)   | 122.2 (0.06)  | 122.1 (-0.0)  | 135.7 (0.11)       | 0.02         | 1151.838275  |
| 25 Gansu          | 223.3 (-)  | 196.1 (-0.12) | 194.8 (-0.01) | 135.8 (-0.3)  | 157.7 (0.16)   | 160.5 (0.02)   | 142.1 (-0.11)  | 127.1 (-0.11) | 125.5 (-0.01) | 118.8 (-0.05)      | -0.06        | 1581.645067  |
| 26 Guizhou        | 168.9 (-)  | 168.7 (-0.0)  | 147.7 (-0.12) | 126.6 (-0.14) | 116.2 (0.08)   | 112.1 (-0.04)  | 101.5 (-0.09)  | 87.1 (-0.14)  | 80.9 (-0.07)  | 67.7 (-0.16)       | -0.10        | 1177.469240  |
| 27 Beijing        | - (-)      | 189.4 (-)     | 205.9 (0.09)  | 132.9 (-0.35) | 132.5 (-0.0)   | 2.9 (-0.98)    | 73.5 (24.6)    | 77.3 (0.05)   | 70.5 (-0.09)  | 56.9 (-0.19)       | 2.89         | 941.896195   |
| 28 Qinghai        | 32.2 (-)   | 32.4 (0.01)   | 28.4 (-0.12)  | 25.7 (-0.1)   | 24.7 (-0.04)   | 20.6 (-0.17)   | 20.6 (0.0)     | 68.8 (2.34)   | 53.2 (-0.23)  | 52.7 (-0.01)       | 0.19         | 359.324602   |
| 29 Hainan         | 48.1 (-)   | 43.7 (-0.09)  | 43.0 (-0.02)  | 37.6 (-0.13)  | 40.1 (0.07)    | 49.3 (0.23)    | 38.0 (0.23)    | 44.9 (0.18)   | 43.8 (-0.02)  | 40.4 (-0.08)       | -0.01        | 428.836500   |

The table indicates each province's total wastewater emissions (in 100M tons) by year. The number in parenthesis represents the year-to-year percentage change. The column *average YtY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998 and the last column, *sum period* is the total emission over the period released in the atmosphere.



### Yearly change SO2 emission by province

| province_en | 1998           | 1999      | 2000          | 2001          | 2002          | 2003          | 2004          | 2005          | 2006          | 2007          | average YtY change | change 98-07 | sum period        |
|-------------|----------------|-----------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|--------------------|--------------|-------------------|
| 0           | Guangxi        | 223.4 (-) | 186.4 (-0.17) | 319.8 (0.72)  | 304.4 (-0.05) | 322.5 (0.06)  | 372.7 (0.16)  | 449.6 (0.21)  | 463.4 (0.03)  | 529.8 (0.14)  | 520.1 (-0.02)      | 0.12         | 3692.184540       |
| 1           | Shandong       | 139.1 (-) | 455.2 (2.27)  | 426.9 (-0.06) | 465.5 (0.09)  | 390.5 (-0.16) | 413.2 (0.06)  | 532.1 (0.28)  | 508.8 (-0.15) | 518.3 (0.02)  | 518.3 (0.02)       | 0.28         | 4446.091864       |
| 2           | Hebei          | 349.3 (-) | 293.2 (-0.16) | 324.6 (0.11)  | 315.9 (-0.03) | 338.6 (0.07)  | 343.6 (0.01)  | 439.2 (0.29)  | 455.7 (0.04)  | 492.2 (0.03)  | 492.2 (0.03)       | 0.04         | 3830.489540       |
| 3           | Sichuan        | 237.8 (-) | 231.5 (-0.03) | 355.5 (0.54)  | 507.0 (0.43)  | 412.4 (-0.19) | 413.6 (0.0)   | 501.9 (0.21)  | 467.1 (-0.07) | 485.8 (0.04)  | 471.0 (-0.03)      | 0.10         | 4083.785113       |
| 4           | Liaoning       | 0.0 (-)   | 339.7 (-)     | 304.9 (-0.1)  | 243.2 (-0.2)  | 246.0 (0.01)  | 226.5 (-0.08) | 243.5 (0.07)  | 434.4 (0.78)  | 458.9 (0.06)  | 444.2 (-0.03)      | -            | 2941.379716       |
| 5           | Jiangsu        | 335.1 (-) | 314.5 (-0.06) | 330.5 (0.05)  | 365.8 (0.11)  | 372.9 (0.02)  | 410.1 (0.1)   | 423.9 (0.03)  | 465.0 (0.1)   | 450.1 (-0.03) | 425.1 (-0.06)      | 0.03         | 3893.030773       |
| 6           | Shanxi         | 228.8 (-) | 259.5 (0.13)  | 210.0 (-0.19) | 322.5 (0.54)  | 355.2 (0.1)   | 338.1 (-0.05) | 434.6 (0.29)  | 398.4 (-0.08) | 407.9 (0.02)  | 422.7 (0.04)       | 0.09         | 1.01 3377.674284  |
| 7           | Guangdong      | 222.1 (-) | 215.3 (-0.03) | 262.4 (0.22)  | 325.7 (0.24)  | 261.3 (-0.2)  | 293.7 (0.12)  | 263.1 (-0.1)  | 245.3 (-0.07) | 228.6 (-0.07) | 414.3 (0.81)       | 0.10         | 2731.654103       |
| 8           | Henan          | 229.0 (-) | 210.7 (-0.08) | 214.8 (0.02)  | 259.8 (0.21)  | 212.1 (-0.18) | 240.3 (0.13)  | 348.5 (0.45)  | 355.4 (0.02)  | 394.4 (0.11)  | 410.6 (0.04)       | 0.08         | 0.91 2875.573922  |
| 9           | Hunan          | 355.5 (-) | 320.5 (-0.1)  | 356.9 (0.11)  | 319.9 (-0.1)  | 340.9 (0.07)  | 322.2 (-0.06) | 395.2 (0.23)  | 393.5 (-0.0)  | 406.4 (0.03)  | 390.9 (-0.04)      | 0.02         | 0.10 3601.938757  |
| 10          | Hubei          | 221.9 (-) | 206.4 (-0.07) | 192.3 (-0.07) | 204.1 (0.06)  | 206.2 (0.01)  | 211.3 (0.03)  | 289.8 (0.37)  | 270.6 (-0.07) | 262.0 (-0.03) | 269.4 (0.03)       | 0.03         | 0.40 2333.997565  |
| 11          | Chongqing      | 123.1 (-) | 107.1 (-0.13) | 110.4 (0.03)  | 155.5 (0.41)  | 137.7 (0.01)  | 208.1 (0.51)  | 259.9 (0.25)  | 193.9 (-0.25) | 265.0 (0.37)  | 268.5 (0.01)       | 0.12         | 1.43 1829.215357  |
| 12          | Inner Mongolia | 158.6 (-) | 138.4 (-0.13) | 120.8 (-0.13) | 126.8 (0.05)  | 143.9 (0.13)  | 162.9 (0.13)  | 316.4 (0.94)  | 350.2 (0.11)  | 371.8 (0.06)  | 265.3 (-0.29)      | 0.10         | 1.20 2155.054234  |
| 13          | Shaanxi        | 121.7 (-) | 96.0 (-0.21)  | 119.0 (0.24)  | 133.7 (0.12)  | 128.1 (-0.04) | 170.9 (0.33)  | 156.8 (-0.08) | 195.2 (0.25)  | 265.4 (0.36)  | 261.5 (-0.01)      | 0.11         | 1.20 1648.291130  |
| 14          | Zhejiang       | 207.6 (-) | 200.3 (-0.04) | 203.7 (0.02)  | 203.0 (-0.0)  | 220.2 (0.08)  | 223.6 (0.02)  | 250.8 (0.12)  | 247.2 (-0.01) | 249.5 (0.01)  | 255.0 (0.02)       | 0.02         | 0.25 2260.950373  |
| 15          | Jiangxi        | - (-)     | - (-)         | 84.4 (-)      | 97.5 (0.16)   | 93.0 (-0.05)  | 122.4 (0.32)  | 161.0 (0.32)  | 194.2 (0.21)  | 225.8 (0.16)  | 213.7 (-0.05)      | 0.15         | 1.53 1191.926260  |
| 16          | Fujian         | 70.7 (-)  | 56.8 (-0.2)   | 72.4 (0.28)   | 63.2 (-0.13)  | 57.8 (-0.09)  | 61.3 (0.06)   | 106.4 (0.74)  | 204.3 (0.92)  | 198.7 (-0.03) | 212.3 (0.07)       | 0.18         | 1.93 1103.772231  |
| 17          | Anhui          | 106.6 (-) | 112.7 (0.06)  | 104.4 (-0.07) | 170.3 (0.63)  | 159.6 (-0.06) | 133.7 (-0.16) | 158.1 (0.18)  | 195.0 (0.23)  | 0.0 (-1.0)    | 192.7 (-)          | -            | 0.85 1333.083496  |
| 18          | Guizhou        | 320.0 (-) | 297.2 (-0.07) | 292.5 (-0.02) | 223.8 (-0.23) | 242.2 (0.08)  | 198.6 (-0.18) | 195.4 (-0.02) | 193.8 (-0.01) | 172.3 (-0.11) | 192.0 (0.11)       | -0.05        | -0.34 2327.822944 |
| 19          | Yunnan         | 190.9 (-) | 103.8 (-0.46) | 96.2 (-0.07)  | 94.9 (-0.01)  | 109.3 (0.15)  | 109.3 (-0.0)  | 117.8 (0.08)  | 173.3 (0.47)  | 181.0 (0.04)  | 188.9 (0.04)       | 0.03         | 0.96 1365.431712  |
| 20          | Xinjiang       | 59.8 (-)  | 66.5 (0.11)   | 68.6 (0.03)   | 71.7 (0.05)   | 76.2 (0.06)   | 89.6 (0.18)   | 159.0 (0.77)  | 129.4 (-0.19) | 132.2 (0.02)  | 168.8 (0.28)       | 0.15         | 1.46 1021.800779  |
| 21          | Gansu          | 229.4 (-) | 171.9 (-0.25) | 212.7 (0.24)  | 195.4 (-0.08) | 264.9 (0.36)  | 279.2 (0.05)  | 268.4 (-0.04) | 279.2 (0.04)  | 268.3 (-0.04) | 148.2 (-0.45)      | -0.30        | 2317.679606       |
| 22          | Jilin          | 64.9 (-)  | 62.4 (-0.04)  | 63.1 (0.01)   | 60.9 (-0.04)  | 48.2 (-0.21)  | 57.0 (0.18)   | 63.4 (0.11)   | 85.3 (0.35)   | 86.3 (0.01)   | 98.1 (0.14)        | 0.06         | 0.56 689.557936   |
| 23          | Heilongjiang   | 3.7 (-)   | 59.0 (15.05)  | 61.9 (0.05)   | 61.4 (-0.01)  | 62.4 (0.02)   | 55.8 (-0.11)  | 103.0 (0.85)  | 97.1 (-0.06)  | 96.7 (-0.0)   | 97.0 (0.0)         | 1.75         | 0.57 697.922939   |
| 24          | Shanghai       | 125.5 (-) | 115.0 (-0.08) | 120.9 (0.05)  | 102.3 (-0.15) | 102.8 (0.01)  | 102.3 (-0.01) | 106.8 (0.04)  | 98.4 (-0.08)  | 93.1 (-0.05)  | 91.2 (-0.02)       | -0.25        | 1058.436348       |
| 25          | Ningxia        | 86.3 (-)  | 42.9 (-0.5)   | 44.9 (0.05)   | 26.2 (-0.42)  | 40.8 (0.56)   | 40.3 (-0.01)  | 42.6 (0.06)   | 46.4 (0.09)   | 58.1 (0.25)   | 77.5 (0.33)        | 0.05         | 0.73 505.820347   |
| 26          | Tianjin        | - (-)     | - (-)         | 49.5 (-)      | 50.0 (0.01)   | 43.5 (-0.13)  | 41.8 (-0.04)  | 39.3 (-0.06)  | 67.3 (0.71)   | 58.2 (-0.14)  | 63.8 (0.1)         | 0.06         | 0.29 413.438706   |
| 27          | Qinghai        | 7.2 (-)   | 7.6 (0.07)    | 9.2 (0.21)    | 6.9 (-0.26)   | 6.9 (0.0)     | 7.4 (0.08)    | 9.7 (0.3)     | 48.0 (3.95)   | 39.4 (-0.18)  | 42.1 (0.07)        | 0.47         | 3.56 184.351011   |
| 28          | Beijing        | - (-)     | 41.1 (-)      | 37.8 (-0.08)  | 29.8 (-0.21)  | 26.6 (-0.11)  | 0.0 (-1.0)    | 18.6 (1610.3) | 18.5 (-0.0)   | 18.7 (0.01)   | 16.4 (-0.12)       | 201.10       | -0.57 207.437536  |
| 29          | Hainan         | 5.1 (-)   | 5.4 (0.06)    | 4.7 (-0.13)   | 3.6 (-0.24)   | 5.5 (0.54)    | 5.9 (0.07)    | 5.9 (0.02)    | 6.2 (0.05)    | 6.7 (0.08)    | 8.4 (0.25)         | 0.08         | 0.79 57.379513    |

The table indicates each province's total SO2 emissions (in 10M tons) by year. The number in parenthesis represents the year-to-year percentage change. The column *average YtY change* indicates the average percentage change over time. The column *change 98-07* indicates the percentage change between 2007 and 1998 and the last column, *sum period* is the total emission over the period released in the atmosphere.

## Contribution of the top polluted sectors to the total wastewater emission

| year | province_en    | 1998     | 1999     | 2000     | 2001     | 2002     | 2003     | 2004     | 2005     | 2006     | 2007     |
|------|----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 0    | Jiangsu        | 8 (21.9) | 8 (25.6) | 8 (23.8) | 8 (42.3) | 7 (28.5) | 8 (36.7) | 8 (45.9) | 7 (45.4) | 8 (51.1) | 8 (53.1) |
| 1    | Shandong       | 8 (6.1)  | 8 (24.3) | 8 (18.6) | 8 (24.2) | 8 (23.0) | 7 (29.7) | 7 (27.4) | 7 (37.0) | 8 (27.4) | 8 (44.6) |
| 2    | Guangdong      | 8 (22.9) | 8 (28.8) | 8 (33.7) | 8 (28.9) | 8 (33.8) | 8 (35.9) | 8 (35.6) | 7 (34.0) | 8 (32.9) | 8 (44.0) |
| 3    | Hebei          | 8 (15.8) | 8 (11.3) | 8 (11.3) | 7 (19.1) | 7 (16.7) | 8 (20.3) | 7 (35.7) | 7 (29.0) | 7 (35.8) | 7 (38.8) |
| 4    | Henan          | 7 (16.0) | 7 (17.6) | 8 (18.3) | 7 (17.0) | 8 (22.4) | 7 (17.8) | 7 (20.1) | 7 (21.5) | 7 (26.3) | 7 (31.8) |
| 5    | Zhejiang       | 8 (16.8) | 8 (23.2) | 8 (26.4) | 8 (24.2) | 8 (25.9) | 8 (27.7) | 8 (30.9) | 8 (31.7) | 7 (29.5) | 7 (31.7) |
| 6    | Chongqing      | 7 (6.6)  | 8 (4.2)  | 7 (6.2)  | 8 (8.4)  | 8 (6.5)  | 7 (14.9) | 8 (24.0) | 7 (11.2) | 7 (23.3) | 8 (23.1) |
| 7    | Hubei          | 8 (19.0) | 7 (20.3) | 7 (17.2) | 7 (18.1) | 7 (13.6) | 8 (13.2) | 7 (17.2) | 7 (20.3) | 7 (19.3) | 7 (21.9) |
| 8    | Fujian         | 8 (12.7) | 8 (17.7) | 8 (18.8) | 8 (13.0) | 8 (17.6) | 8 (16.8) | 8 (15.7) | 8 (18.9) | 8 (20.5) | 8 (19.5) |
| 9    | Sichuan        | 7 (13.7) | 8 (17.6) | 7 (18.9) | 8 (16.7) | 8 (23.9) | 8 (21.2) | 8 (22.8) | 8 (32.6) | 8 (22.5) | 8 (18.3) |
| 10   | Liaoning       | - (-)    | 8 (16.5) | 7 (14.4) | 7 (16.4) | 7 (14.5) | 7 (11.2) | 7 (11.4) | 7 (12.5) | 7 (17.3) | 7 (17.3) |
| 11   | Guangxi        | 8 (9.2)  | 7 (7.9)  | 7 (9.4)  | 8 (7.7)  | 7 (6.9)  | 7 (10.5) | 7 (15.7) | 7 (14.9) | 7 (15.1) | 7 (15.4) |
| 12   | Anhui          | 7 (7.9)  | 7 (12.6) | 7 (11.3) | 7 (8.8)  | 7 (12.7) | 7 (8.7)  | 7 (10.3) | 7 (15.5) | 8 (15.6) | 7 (14.3) |
| 13   | Jiangxi        | - (-)    | - (-)    | 7 (9.3)  | 6 (7.7)  | 7 (7.8)  | 7 (7.4)  | 7 (6.3)  | 7 (12.0) | 7 (11.2) | 7 (12.9) |
| 14   | Jilin          | 7 (6.0)  | 7 (4.8)  | 7 (5.5)  | 8 (8.1)  | 7 (7.2)  | 7 (7.9)  | 7 (7.5)  | 7 (13.5) | 7 (13.7) | 7 (12.5) |
| 15   | Heilongjiang   | 5 (0.4)  | 8 (12.4) | 8 (12.3) | 7 (13.5) | 7 (12.3) | 7 (9.5)  | 7 (8.7)  | 7 (7.4)  | 7 (7.4)  | 7 (11.1) |
| 16   | Xinjiang       | 6 (3.0)  | 7 (3.7)  | 6 (6.7)  | 6 (6.4)  | 7 (6.7)  | 7 (4.3)  | 7 (5.2)  | 6 (7.0)  | 6 (8.3)  | 6 (10.2) |
| 17   | Shanghai       | 8 (18.7) | 7 (17.3) | 7 (16.0) | 7 (13.0) | 7 (11.4) | 8 (11.6) | 8 (9.0)  | 8 (11.9) | 8 (12.8) | 8 (10.1) |
| 18   | Hunan          | 7 (28.5) | 8 (21.7) | 8 (15.4) | 8 (15.8) | 7 (18.8) | 7 (12.9) | 7 (9.0)  | 7 (16.0) | 8 (12.9) | 8 (10.0) |
| 19   | Shanxi         | 8 (5.0)  | 8 (3.6)  | 8 (4.3)  | 8 (3.6)  | 7 (3.9)  | 7 (4.3)  | 7 (4.5)  | 7 (4.2)  | 7 (7.1)  | 7 (6.9)  |
| 20   | Inner Mongolia | 7 (4.1)  | 7 (4.1)  | 7 (3.5)  | 7 (3.7)  | 7 (3.1)  | 7 (4.3)  | 7 (3.3)  | 7 (4.8)  | 6 (7.2)  | 6 (6.9)  |
| 21   | Shaanxi        | 7 (8.7)  | 7 (6.5)  | 7 (6.2)  | 7 (6.5)  | 8 (4.9)  | 7 (7.5)  | 7 (7.5)  | 7 (7.3)  | 7 (7.4)  | 7 (6.7)  |
| 22   | Tianjin        | - (-)    | - (-)    | 7 (4.5)  | 7 (6.2)  | 8 (5.6)  | 8 (4.7)  | 8 (6.0)  | 7 (5.1)  | 7 (5.4)  | 7 (6.2)  |
| 23   | Gansu          | 7 (7.3)  | 7 (4.4)  | 7 (4.8)  | 8 (5.1)  | 7 (4.7)  | 7 (5.0)  | 8 (4.4)  | 7 (4.6)  | 7 (4.2)  | 7 (4.6)  |
| 24   | Yunnan         | 6 (5.4)  | 7 (3.8)  | 7 (2.8)  | 7 (3.4)  | 6 (4.3)  | 6 (3.1)  | 6 (3.4)  | 6 (3.4)  | 6 (3.0)  | 7 (2.8)  |
| 25   | Guizhou        | 7 (4.9)  | 8 (4.3)  | 7 (6.5)  | 7 (4.1)  | 7 (5.1)  | 8 (3.3)  | 7 (3.7)  | 7 (4.2)  | 7 (2.6)  | 7 (2.6)  |
| 26   | Beijing        | - (-)    | 8 (5.2)  | 7 (6.9)  | 7 (5.5)  | 7 (5.4)  | - (-)    | 7 (2.7)  | 7 (2.8)  | 7 (2.7)  | 7 (2.5)  |
| 27   | Ningxia        | 6 (1.5)  | 6 (1.8)  | 6 (2.4)  | 6 (1.4)  | 6 (1.9)  | 5 (1.7)  | 5 (2.0)  | 6 (3.3)  | 5 (1.6)  | 6 (2.1)  |
| 28   | Qinghai        | 6 (0.9)  | 5 (1.2)  | 6 (0.7)  | 5 (0.9)  | 5 (1.1)  | 5 (0.4)  | 4 (0.6)  | 5 (5.0)  | 5 (1.2)  | 5 (1.1)  |
| 29   | Hainan         | 6 (1.7)  | 7 (0.9)  | 7 (0.9)  | 6 (0.8)  | 5 (0.7)  | 5 (0.6)  | 5 (0.6)  | 5 (0.5)  | 5 (0.7)  | 5 (1.0)  |

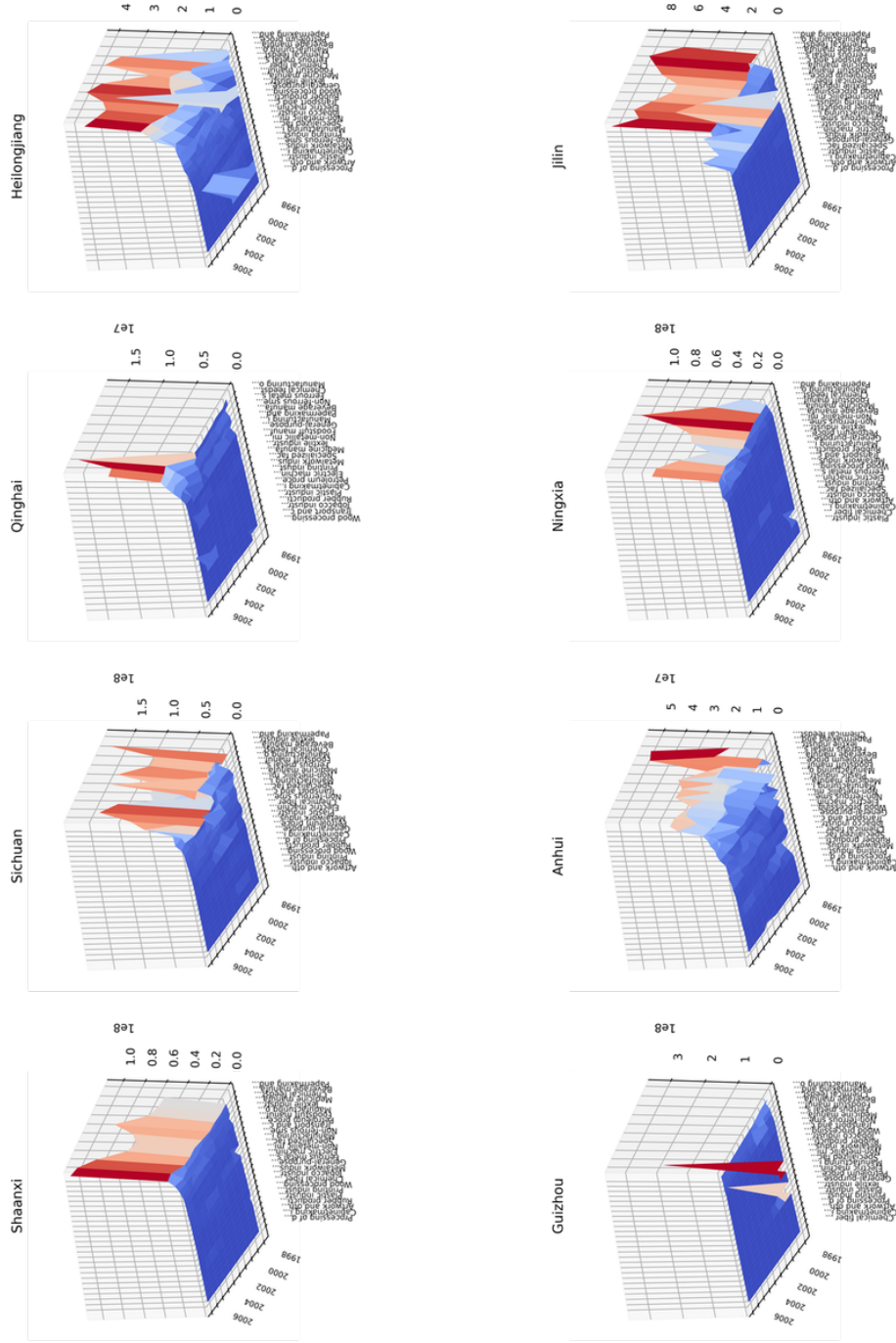
This table shows the sector's contribution to the total wastewater emission (in 100M tons). In this table, we count the number of sectors accounting for at least 75% of the total wastewater emissions. The number in parenthesis indicates the 75% threshold.

### Contribution of the top polluted sectors to the total SO2 emission

| year | province_en    | 1998    | 1999     | 2000     | 2001     | 2002     | 2003     | 2004     | 2005     | 2006     | 2007     |
|------|----------------|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 0    | Shandong       | 8 (4.6) | 8 (16.2) | 8 (11.7) | 8 (13.0) | 8 (9.4)  | 7 (12.9) | 7 (13.5) | 7 (13.0) | 8 (11.2) | 8 (21.6) |
| 1    | Sichuan        | 7 (5.4) | 8 (6.1)  | 7 (8.0)  | 8 (9.0)  | 8 (13.0) | 8 (11.8) | 8 (12.1) | 8 (11.6) | 8 (6.6)  | 8 (9.2)  |
| 2    | Hebei          | 8 (3.1) | 8 (4.8)  | 8 (4.9)  | 7 (3.7)  | 7 (5.4)  | 8 (5.0)  | 7 (7.4)  | 7 (7.7)  | 7 (10.7) | 7 (8.2)  |
| 3    | Henan          | 7 (7.5) | 7 (4.0)  | 8 (5.1)  | 7 (3.8)  | 8 (4.0)  | 7 (3.9)  | 7 (5.7)  | 7 (6.4)  | 7 (6.8)  | 7 (7.8)  |
| 4    | Jiangsu        | 8 (5.3) | 8 (5.0)  | 8 (6.7)  | 8 (7.0)  | 7 (6.3)  | 8 (7.0)  | 8 (5.2)  | 7 (5.8)  | 8 (5.5)  | 8 (7.3)  |
| 5    | Zhejiang       | 8 (3.2) | 8 (3.1)  | 8 (4.1)  | 8 (3.5)  | 8 (3.9)  | 8 (3.4)  | 8 (3.6)  | 8 (4.7)  | 7 (6.4)  | 7 (7.0)  |
| 6    | Chongqing      | 7 (3.4) | 8 (1.8)  | 7 (2.3)  | 8 (1.9)  | 8 (2.3)  | 7 (3.1)  | 8 (1.8)  | 7 (2.3)  | 7 (6.3)  | 8 (6.0)  |
| 7    | Jilin          | 7 (1.8) | 7 (2.8)  | 7 (2.4)  | 8 (2.1)  | 7 (1.6)  | 7 (3.9)  | 7 (4.0)  | 7 (5.3)  | 7 (4.7)  | 7 (5.9)  |
| 8    | Guangdong      | 8 (5.0) | 8 (7.1)  | 8 (6.7)  | 8 (7.7)  | 8 (5.3)  | 8 (5.6)  | 8 (6.4)  | 7 (4.7)  | 8 (4.0)  | 8 (5.5)  |
| 9    | Guangxi        | 8 (4.1) | 7 (4.1)  | 7 (7.1)  | 8 (3.0)  | 7 (4.1)  | 7 (7.7)  | 7 (9.7)  | 7 (6.7)  | 7 (9.9)  | 7 (5.4)  |
| 10   | Inner Mongolia | 7 (4.4) | 7 (4.3)  | 7 (3.5)  | 7 (3.6)  | 7 (4.0)  | 7 (3.4)  | 7 (3.4)  | 7 (4.2)  | 6 (8.5)  | 6 (5.3)  |
| 11   | Jiangxi        | - (-)   | - (-)    | 7 (2.5)  | 6 (2.9)  | 7 (2.4)  | 7 (2.2)  | 7 (2.7)  | 7 (4.0)  | 7 (4.2)  | 7 (5.0)  |
| 12   | Liaoning       | - (-)   | 8 (7.4)  | 7 (7.3)  | 7 (6.7)  | 7 (5.2)  | 7 (3.6)  | 7 (4.2)  | 7 (6.7)  | 7 (5.9)  | 7 (4.9)  |
| 13   | Hunan          | 7 (6.3) | 8 (5.9)  | 8 (5.8)  | 8 (6.8)  | 7 (5.4)  | 7 (3.7)  | 7 (5.0)  | 7 (4.4)  | 8 (4.9)  | 8 (4.7)  |
| 14   | Hubei          | 8 (4.4) | 7 (4.0)  | 7 (3.8)  | 7 (4.0)  | 7 (4.7)  | 8 (3.9)  | 7 (5.7)  | 7 (5.8)  | 7 (4.7)  | 7 (4.6)  |
| 15   | Anhui          | 7 (1.1) | 7 (2.0)  | 7 (2.1)  | 7 (3.1)  | 7 (2.8)  | 7 (3.0)  | 7 (3.1)  | 7 (4.7)  | - (-)    | 7 (4.6)  |
| 16   | Guizhou        | 7 (4.8) | 8 (6.8)  | 7 (8.7)  | 7 (7.1)  | 7 (6.8)  | 8 (4.7)  | 7 (5.1)  | 7 (5.1)  | 7 (3.0)  | 7 (4.6)  |
| 17   | Xinjiang       | 6 (3.2) | 7 (3.1)  | 6 (2.8)  | 6 (3.1)  | 7 (2.7)  | 7 (3.2)  | 7 (3.2)  | 6 (3.9)  | 6 (4.0)  | 6 (4.5)  |
| 18   | Shaanxi        | 7 (4.0) | 7 (3.8)  | 7 (2.7)  | 7 (3.9)  | 8 (2.8)  | 7 (3.8)  | 7 (4.3)  | 7 (3.6)  | 7 (4.6)  | 7 (3.8)  |
| 19   | Fujian         | 8 (1.4) | 8 (1.4)  | 8 (2.5)  | 8 (1.7)  | 8 (1.7)  | 8 (1.6)  | 8 (2.2)  | 8 (3.5)  | 8 (3.3)  | 8 (3.5)  |
| 20   | Heilongjiang   | 5 (0.2) | 8 (2.9)  | 8 (3.1)  | 7 (3.2)  | 7 (3.2)  | 7 (2.8)  | 7 (3.3)  | 7 (4.0)  | 7 (2.8)  | 7 (3.2)  |
| 21   | Shanxi         | 8 (4.8) | 8 (4.1)  | 8 (2.7)  | 8 (2.9)  | 7 (3.3)  | 7 (4.3)  | 7 (5.5)  | 7 (3.6)  | 7 (2.9)  | 7 (3.1)  |
| 22   | Yunnan         | 6 (2.2) | 7 (2.3)  | 7 (2.1)  | 7 (1.9)  | 6 (2.4)  | 6 (1.9)  | 6 (4.2)  | 6 (3.5)  | 6 (3.5)  | 7 (2.7)  |
| 23   | Shanghai       | 8 (3.3) | 7 (2.8)  | 7 (2.9)  | 7 (2.2)  | 7 (2.1)  | 8 (1.8)  | 8 (1.8)  | 8 (1.3)  | 8 (1.3)  | 8 (1.9)  |
| 24   | Ningxia        | 6 (1.6) | 6 (1.3)  | 6 (0.8)  | 6 (0.9)  | 6 (1.4)  | 5 (1.9)  | 5 (1.5)  | 6 (2.0)  | 5 (1.8)  | 6 (1.9)  |
| 25   | Gansu          | 7 (1.7) | 7 (1.4)  | 7 (1.7)  | 8 (1.7)  | 7 (1.5)  | 7 (1.8)  | 8 (1.2)  | 7 (1.8)  | 7 (2.2)  | 7 (1.7)  |
| 26   | Tianjin        | - (-)   | - (-)    | 7 (1.2)  | 7 (1.7)  | 8 (1.2)  | 8 (1.0)  | 8 (0.9)  | 7 (0.7)  | 7 (0.9)  | 7 (1.1)  |
| 27   | Qinghai        | 6 (0.2) | 5 (0.3)  | 6 (0.2)  | 5 (0.3)  | 5 (0.3)  | 5 (0.3)  | 4 (0.7)  | 5 (4.9)  | 5 (1.1)  | 5 (1.0)  |
| 28   | Beijing        | - (-)   | 8 (1.2)  | 7 (1.0)  | 7 (0.9)  | 7 (0.7)  | - (-)    | 7 (0.2)  | 7 (0.5)  | 7 (0.3)  | 7 (0.3)  |
| 29   | Hainan         | 6 (0.1) | 7 (0.1)  | 7 (0.1)  | 6 (0.2)  | 5 (0.2)  | 5 (0.3)  | 5 (0.2)  | 5 (0.1)  | 5 (0.1)  | 5 (0.1)  |

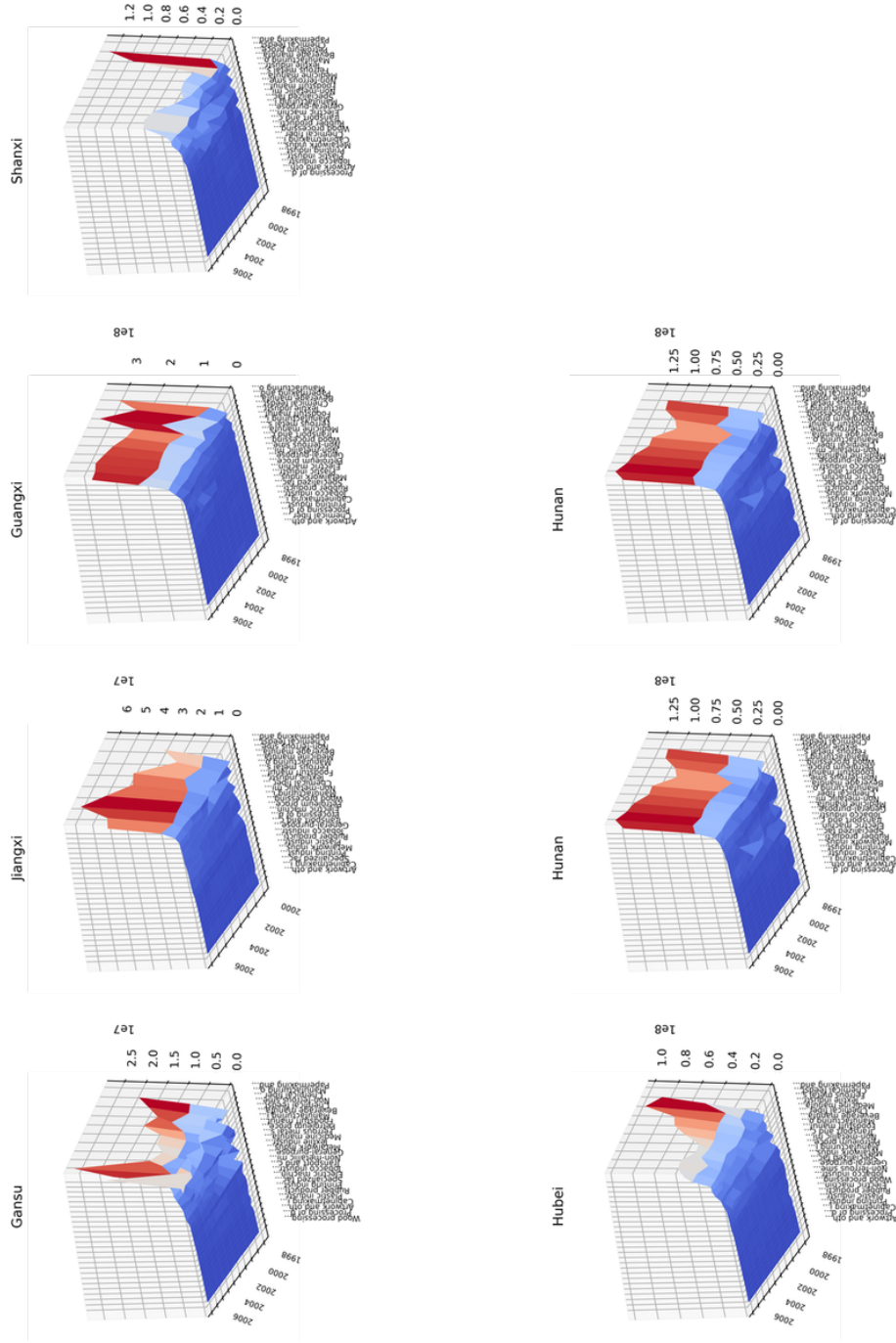
This table shows the sector's contribution to the total SO2 emission (in 10M tons). In this table, we count the number of sectors accounting for at least 75% of the total wastewater emissions. The number in parenthesis indicates the 75% threshold.

Figure 1.15: Emission of COD by province-industry and year: very poor provinces



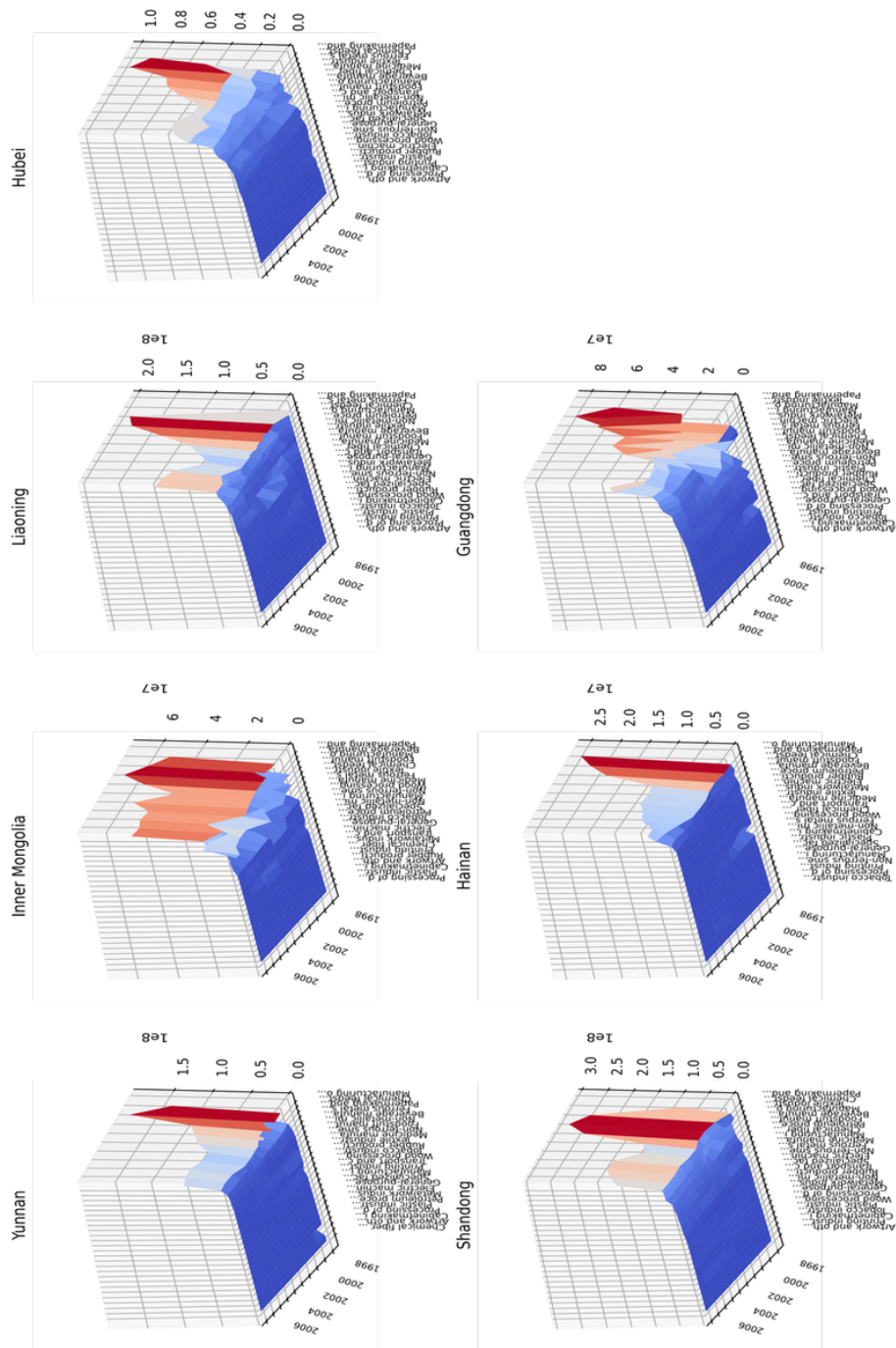
**Note:** The graph plots the distribution of COD emissions in the poorest provinces. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

Figure 1.16: Emission of COD by province-industry and year: poor provinces



**Note:** The graph plots the distribution of COD emissions (in 10M tons) in the poor provinces. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

Figure 1.17: Emission of COD by province-industry and year: middle income provinces

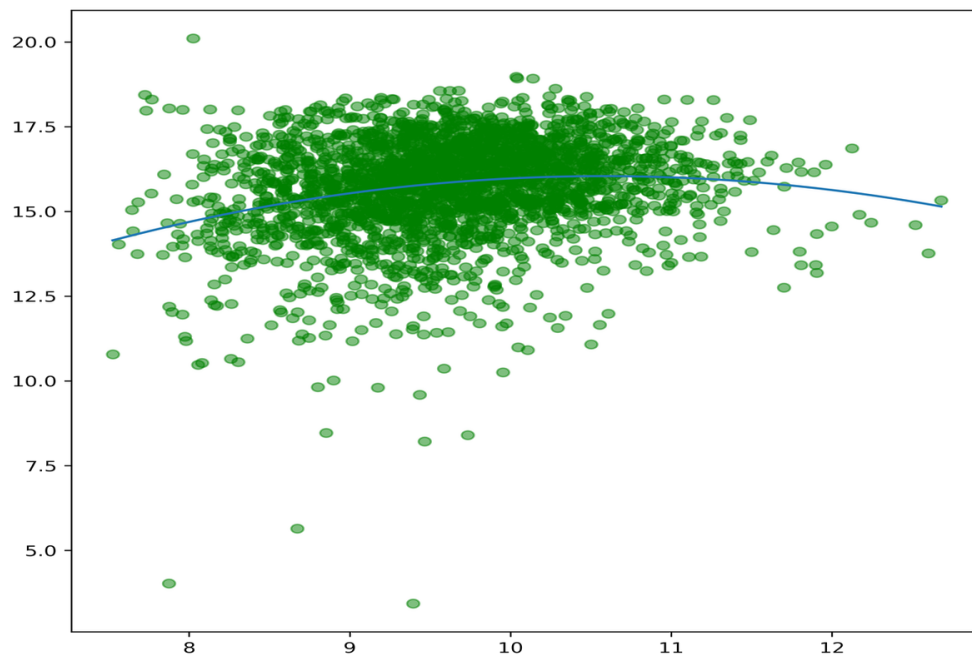


**Note:** The graph plots the distribution of COD emissions (in 10M tons) in the middle-income provinces. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.





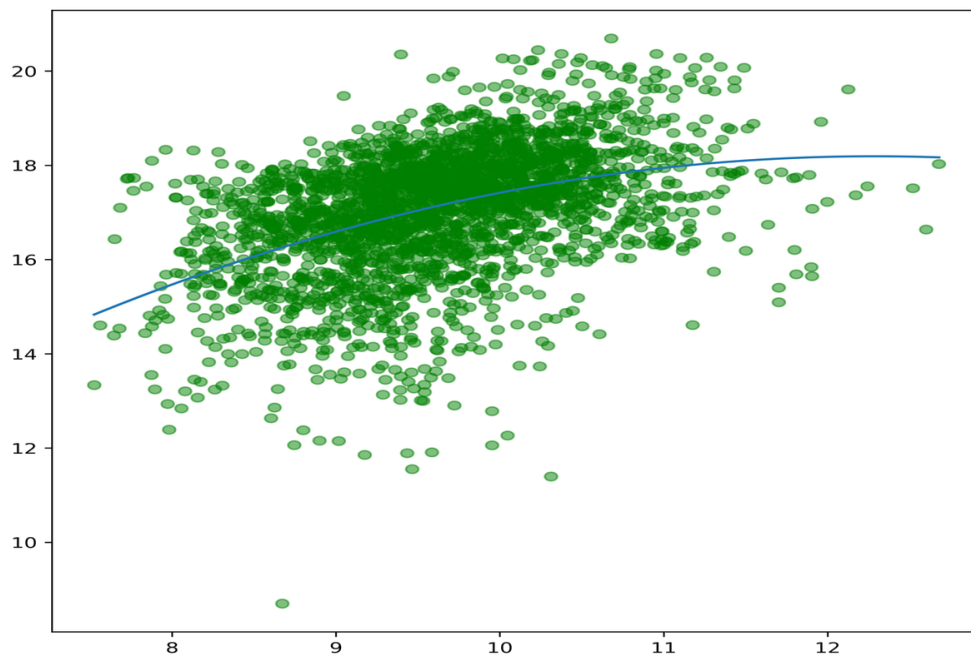
**Figure 1.19: COD Environmental Kuznets Curve**



**Note:** The graph plots the relationship between the city GDP per capita and COD emission (in log). The line represents the quadratic form and shows a turning point at roughly 60.000RMB. **Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.



**Figure 1.20: Wastewater Environmental Kuznets Curve**



**Note:** The graph plots the relationship between the city GDP per capita and COD emission (in log). The line represents the quadratic form and shows no turning point.  
**Source:** Annual survey of Chinese enterprises collected by the Ministry of Environmental Protection.

## Chapter 2

Internal finance, financial constraint,  
and pollution emissions: evidence  
from China

## 2.1 Introduction

Concern about environmental issues is growing dramatically in China because of its environmental disasters and poor air quality. The country has experienced numerous disasters impacting the population's health and nourishing political discontent. China is a major global air polluter and has significantly increased sulfur dioxide emissions ( $SO_2$ ) since it entered the WTO in 2001. Meanwhile, it has experienced an unprecedented growth rate fueled mainly by the private sectors through the availability of internally generated funds (Guariglia et al. 2011), as credit constraints are prevalent, which leads to a distortion of the firm assets structure. This paper documents the role of credit constraints on  $SO_2$  emissions and internal finance in promoting environmentally friendly growth based on investments in intangible assets.

Reducing the emissions of pollution is a challenge every industrialized and emerging country is facing.<sup>1</sup> While credit constraints is detrimental to growth, recent literature shows that it also has an impact on the environment. Andersen (2017) argues that credit constraints distort asset allocation towards tangible, pollution-driven assets. In contrast, companies disposing of more internal finance can afford to invest in enhanced productive activities or in research and development (R&D), which target a more environmentally friendly growth and align with policies to regulate polluting emissions.<sup>2</sup> Our paper investigates the finance-induced assets' distortion in China. This is an important contribution because China is one of the fastest-growing economies, so addressing a market imperfection could help to fight against pollution. China was, in 2006, the world's most significant emitter of  $SO_2$ , the largest COD emitter in the world, surpassing the United States, and in 2018, still held first place. The country hosts more than half of the most polluted cities in the world, according

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<sup>1</sup>As argued in Gu et al. 2018, the challenge for an emerging country like China is that it has to conduct at the same time and in an economically consistent way its growth and climate-friendly environmental protection strategies

<sup>2</sup>Innovation within firms, measured by research and development expenditure, aims at improving the firm's production process hence fewer inputs per unit of output are needed.

to the WHO.<sup>3</sup> In 2017, it ranked first in the world in terms of the number of natural disasters, surpassing the United States and India.<sup>4</sup> China’s contribution to the climate crisis is emphasized by the OECD.<sup>5</sup>

Our strategy is built upon the model of Andersen (2017), which states credit constraints lead firms to invest in tangible assets, one important driver of pollution emissions. We use the most extensive environmental statistics available in China, collected and maintained by the Ministry of Environmental Protection (MEP). It gathers disaggregated information about the emissions of major pollutants such as sulfur dioxide, our variable of interest. It also covers wastewater, chemical oxygen demand, industrial dust, and all industrial sectors. To our knowledge, only a few studies (Fan et al. 2021; He et al. 2020; Wu et al. 2017; Zhang and Zheng 2019, among others) have used this disaggregated level of pollution emissions in China, allowing us to track most of the industrial emissions of  $SO_2$  during seven consecutive years (2001–2007) at the level of industries and cities. We measure internal finance metrics (proxy by cash flow and current ratio) using the annual surveys of Chinese manufacturing firms conducted by the National Bureau of Statistics of China (NBS). Our dataset allows us to explore the variation of internal finance to explain the change in city-sector  $SO_2$  emissions over time. Following this examination of the determinants of pollution at the city-sector and year level, we use the NBS firm’s level dataset to explain the underlying mechanisms behind the relationship between internal finance and the emissions of  $SO_2$ . The annual surveys of the Chinese manufacturing firms dataset informed the firms’ ownership structure, allowing us to distinguish between SOEs and private, foreign, and domestic companies. We also pay close attention to the intensity of the credit constraint faced by the firms to complement our results. The effect of the availability of internal financing on asset tangibility, TFP or

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<sup>3</sup>In 2013, Shijiazhuang had only 47 days with good air quality.

<sup>4</sup>In 2017, the province of Hunan suffered a direct economic loss of about 59 billion RMB due to natural disasters (National Bureau of Statistics of China; Ministry of Ecology and Environment) More statistics can be found at the following link <https://drive.google.com/open?id=1nq-njkZ-TaQyzH30Ncq1R8hlpFE1InSG>.

<sup>5</sup><https://oecd-development-matters.org/2019/06/20/the-global-souths-contribution-to-the-climate-crisis-and-its-potential-solutions/>.

the purchase of pollution abatement equipment might be different in the most constrained industries.

The results are as follows. First, the distortion of asset allocation toward tangible assets positively correlates with  $SO_2$  emissions. Banking finance is associated with more pollution, and cities with more internal finance are less polluting, all other things being equal. We show that the internal finance-induced pollution reduction is larger for private and domestic enterprise-dominated cities.<sup>6</sup> Total Factor Productivity (TFP) plays a role in reducing  $SO_2$  emissions: an increase in TFP by 10% reduces city emissions of  $SO_2$  by 8%. To sum up, the scarcity of external finance combined with a distorted allocation of banking finance contributes to the pattern of  $SO_2$  emissions. The firm-level data allow us to examine the mechanisms underlying this relationship between finance and pollution observed at the city-sector level over time. We show that firms with more internal finance and more limited access to bank credit (private and domestic firms, as opposed to state-owned and foreign firms) tend to invest more (less) in intangible (tangible) assets and  $R\&D$ . In addition, we provide evidence that the availability of internal finance leads to the purchase of pollution abatement equipment. All of these mechanisms contribute to the reduction of pollutant emissions.

The rest of this paper is organized as follows: The role of internal finance in growth and environmental performance is described in Section 2. Our empirical strategy, data and preliminary evidence are presented in Section 3. Section 4 presents the baseline findings and sources of heterogeneity. Section 5 presents the mechanisms, and finally, the paper concludes in Section 6.

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<sup>6</sup>The banking system often backs up state-owned enterprises in China hence they are not credit constrained. Foreign firms can raise money from their parent company.

## 2.2 Internal/external finance, growth and environmental performance

The link between economic performance and finance is well-established, particularly in developed countries.<sup>7</sup> Cross-country evidence shows that external finance is linked with better economic performances, financed through the credit market or the equity market (Hsu et al. 2014). In China, this link is operating in a specific way. The economy grew at an astonishing rate over the past few decades, fueled mainly by private firms,<sup>8</sup> while it is well-established that the financial market was not allocating resources efficiently during that period.<sup>9</sup> Prior works have also demonstrated a negative link between the credit market and the firms' performance due to lending bias (Chen et al. 2016; Guariglia and Poncet 2008; Hasan et al. 2009).<sup>10</sup> Indeed, state-owned enterprises (SOEs hereafter) are the most prominent loan recipients in China, despite their poor economic performance (Hale and Long 2011). The Chinese government runs the banking system through four banks, which provide 60% of the loans to the economy; among them is a large share of non-performing loans (Allen et al. 2005). To secure a loan, private firms need to rely on their political connections (Cull et al. 2015) or provide much more collateral than their SOEs peers (Brandt and Li 2003). For them, internal finance is key.

Internal finance is also particularly important in driving the pollution emissions, as em-

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<sup>7</sup>For the general case, see the recent meta-analysis in Bijlsma et al. (2018). For the specific case of China, see the recent analysis of Xu and Gui (2021). Besides, the literature has used different proxies to evaluate Chinese economic performance, such as the growth level (Guariglia and Poncet 2008; Hasan et al. 2009), GDP per capita (Boyreau-Debray 2003), total factor productivity (Ayyagari et al. 2010; Chen and Guariglia 2013; Li et al. 2018), assets growth (Guariglia et al. 2011).

<sup>8</sup>Chinese manufacturing enterprises during 1999-2005 accounted for over 90% of China's industrial output (Demetriades et al. 2008).

<sup>9</sup>In regards to this poor functioning, China is not an exception. Most developing economies have poor financial markets, and their equity market is almost nonexistent.

<sup>10</sup>The primary way to get funding in China is through a loan (Hale and Long 2011). By the end of 2002, the banking sector's total assets stood close to 85% of the total assets of the entire financial sector (Ping 2003).

phasized by the flourishing literature on this topic.<sup>11</sup> Andersen (2017) designs a model where private firms suffering from credit constraints invest relatively more in tangible assets, increasing pollution emissions. Ghisetti et al. (2017) assesses the existence of direct negative effects of financial barriers on environmental innovation investment decisions by analyzing small and medium-sized manufacturing firms in Europe. Noailly and Smeets (2021) focus on European patent data and show that innovative clean energy firms may be particularly vulnerable to financing constraints. Using Chinese firm's level data and in the context of the Chinese green credit policy in 2012, Fan et al. (2021) shows that firms with a record of noncompliance with environmental regulations saw a larger increase in the interest rate, decrease in loans, and more difficulty in access to loans. These effects are more pronounced for small and private firms, which calls for a specific policy better adapted to the risk of falling production. De Haas and Popov (2018) uses cross-country level data to evaluate the impact of external finance on the emissions of  $CO_2$ . They find that the emissions of  $CO_2$  are dampened by the equity market's development, while the credit market's impact on aggregated  $CO_2$  emissions is positive and strong. Their conclusions echo the extensive literature on external finance and growth. The equity market is more suited to bear the investment risk related to innovation. At the same time, banks have a lower capacity to assess a project's innovative pertinence and support it.<sup>12</sup>

R&D projects and environmental innovation are often denied external financing in developing countries because of the lack of collateral, which is inherent to them. Tangible assets are more likely to be financed for two main reasons. The first reason is that a tangible asset has a finite monetary value and a physical form. Its liquidity might vary, but it can always

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<sup>11</sup>The empirical literature uses cash flow as a proxy for internal finance (Guariglia et al. 2011). External finance refers to the use of a third party to obtain financing. There are two broad parties: equity market and credit market.

<sup>12</sup>The literature on external finance and investment decisions shows that asymmetric information, moral hazard, and tax considerations are the main mechanisms, which explains why the credit market is not suited to finance innovation. The equity market development helps circumvent the problems inherent to the credit market (Hall and Lerner 2010).

be transacted with a monetary value, so in the event of default, the bank can convert the assets to cash. Secondly, banks lack the skills to judge innovative projects (Ueda 2004). By facing difficulties securing a loan from the banks to finance growth, private firms use their internal finance extensively to invest in research and development, innovative projects, and other forms of growth-oriented projects (Carpenter and Petersen 2002; Chow and Fung 2000; Guariglia et al. 2011; Poncet et al. 2010). Using firm-level data, Li et al. (2018) shows that internal finance significantly increases productivity through innovation, but this effect is limited to private firms. This paper examines whether intangible investments financed by internal funding are directed towards environmentally friendly innovations in the context of public policies to regulate pollutant emissions and the government's desire to reduce them. It is based on an extremely rich database and on the empirical strategy defined in the next section.

## 2.3 Empirical strategy and Data, Preliminary Evidence

### 2.3.1 Empirical strategy and Data

The empirical strategy is designed to evaluate the impact of asset tangibility, internal finance, TFP, and  $SO_2$  removal efficiency on pollution emissions at the city-industry level from 2001 to 2007. More specifically, we estimate the following reduced-form specification, borrowed from Andersen (2017), which states that investing in tangible assets produces more pollution. However, banks only make grants for investments in tangible assets that serve as collateral. Mostly internal finance can fund innovation, R&D, and pollution reduction equipment. These are backed up by a national pollution control policy conducted in China since the early 2000s. This is the reason why a variable *internal finance* is added, next to *asset tangibility*, to include this effect of the internal finance being invested in non-tangible assets in response



to the national policy of regulating pollution emissions.

$$\begin{aligned}
SO_{2cit} = & \alpha_1 \text{asset tangibility}_{cit} + \alpha_2 \text{internal finance}_{cit-1} + \\
& \alpha_3 SO_2 \text{ removing capacity}_{cit} + \alpha_4 \text{TFP}_{cit} + \\
& \beta X_{cit} + \gamma_{it} + \gamma_{ct} + \epsilon_{cit}
\end{aligned} \tag{2.1}$$

$SO_{2cit}$  refers to sulfur dioxide, a colorless, dense, and toxic gas that is highly irritating and dangerous to health when inhaled.  $SO_{2cit}$  is not available at the firms' level,<sup>13</sup> but at the city  $c$ , industry  $i$  and year  $t$ . The Ministry of Environmental Protection (MEP) has collected the primary data source of pollutants and waste in China since 1980. Firms considered heavy polluters are asked to report basic information such as company name, address, and output. They also answer a very detailed questionnaire about their major pollutants' emissions (e.g., wastewater, COD,  $SO_2$ , industrial smoke, and dust). As reported in Jiang et al. (2014) and Wu et al. (2017), the dataset contains information about 85% of pollution emissions from major pollutants in China. The MEP has implemented strict procedures, including unforeseen visits from experts to ensure that these firms have not misreported their emissions. Our analysis is focused on the  $SO_2$  statistics, a primary air pollutant for 29 two-digit industries spread across 284 cities from 2001 to 2007. Furthermore, firms are required to report their investment related to pollution abatement equipment (such as sewage treatment devices and air cleaning devices) and their efficiency in terms of pollution removal.

The National Bureau of Statistics of China's (NBS) mission is to collect and analyze information on China's economy and society throughout its territory, to which end it conducts surveys among all non-state-owned enterprises with sales above 5 million RMB and

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<sup>13</sup>Due to the sensitivity, and sharing pollution firm-level data is not easily feasible, we opted to use city-industry level

state-owned enterprises. The survey is detailed and thorough insofar as it contains detailed information about the name, address, four-digit CIC industry classification, ownership, and financial variables (including output, sales, and fixed assets). The temptation to cheat and not provide true figures is minimized by the fact that, according to Chen et al. (2018), the NBS is not allowed to share information with other agencies (e.g., tax agencies, government). As a result, the survey is regarded as being trustworthy and widely used, e.g., since 1995, to compute statistics such as GDP. We follow Manova (2013) to construct *asset tangibility*<sub>cit</sub> at the firm level by summing the fixed assets, adjusted for depreciation, and divided by total assets. We aggregate firms' asset tangibility at the city-industry-year level to be able to match it with the pollution data.

Our next main variable, *internal finance*<sub>cit-1</sub>, is proxied by cash flow and current ratio. The current ratio is a liquidity ratio that measures a company's ability to pay short-term obligations or those due within one year. Larger values suggest that the company has more liquidity and is less dependent on the credit market. Cash flow is defined as the net income<sup>14</sup> plus depreciation, adjusted to tangible assets.<sup>15</sup> With more cash flow, a firm can optimize its capital efficiency by investing in productive growth-enhancing activities, e.g. proprietary technology or R&D (Li et al. 2018). In China, private firms which generated a large amount of cash could grow at a relatively higher rate, even though they face external credit constraints (Guariglia et al. 2011). Cash flow is commonly used as a proxy for internal finance in the literature (Chen and Guariglia 2013; Chow and Fung 1998, 2000; Guariglia et al. 2011). Following Andersen (2017), both internal finance variables (cash flow and current ratio) are one year lagged,<sup>16</sup> and computed at the city-industry for each year available in the dataset.

We complement the information on the financial situation of firms with the external fi-

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<sup>14</sup>Net income is defined as the difference between profit before tax but after extraordinary income and income tax.

<sup>15</sup>As a robustness check, cash flow is also adjusted to total assets.

<sup>16</sup>We also estimate equation 2.1 using contemporary values for internal finance. Results remained unchanged and are available upon request.

nancial dependency, which is available not at the firm level but at the sector level. This information is, therefore, less disaggregated. We use the industry’s external finance dependency, defined as the industry’s exposure to the banks. The industry’s external finance dependency computation is straightforward—it is the share of capital expenditure not financed with cash flow from operations. Previous works have used US data to proxy for the exposure to external finance (Rajan and Zingales 1998; Claessens and Laeven 2003; Kroszner et al. 2007) and in the context of China (Jarreau and Poncet 2014; Manova et al. 2015; Fan et al. 2015). We use the Chinese data and replicate the methodology proposed by Fan et al. (2015), who used the annual surveys of Chinese manufacturing firms dataset during the years 2004–2006 to aggregate the capital expenditure and cash flow at the two digits industrial level. Fan et al. (2015) argue that the financial pattern between the US and China is almost similar.<sup>17</sup> Tobacco is the least vulnerable sector in the US, while it ranks second in China. The leather products industry is the second least vulnerable in the US and the fifth least vulnerable in China. Table 2.19 in the appendix gives the value of financial dependence for the 29 industries in China. The average value is -.57, and industries with a high technological requirement are also the most vulnerable. The *Petroleum* industry and *Processing of Nuclear Fuel* industries are at the bottom of the table, stressing their high reliance on credit.

When a firm needs to remove pollution, one option is to invest in pollution abatement equipment. Our dataset includes a variable that reports the theoretical capacity of an industry to remove  $SO_2$  by kilogram/hour. We use this variable to compute  $SO_2$  removing capacity<sub>cit</sub>, set equal to the  $SO_2$  removing capacity at the city-industry level divided by the city-industry total sales.

Another coefficient of interest is total factor productivity,  $TFP_{cit}$ . We resort to the

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<sup>17</sup>Unlike the US methodology, which uses the median over time, the authors use the aggregate value from the Chinese data because about 68% of the observations have 0 capital expenditure.

Olley and Pakes (1996) approach to compute it at the firm-level.<sup>18</sup> We use a Cobb-Douglas function with three factors: labor, capital, and intermediate input. We average  $TFP_{cit}$  at the city-industry and year level.  $TFP_{cit}$  is a significant component of growth efficiency in China (Brandt et al. 2012). The change in pollution induced by TFP can be positive or negative, depending on whether TFP leads to adopting new technologies stemming from environmentally friendly innovation (Grossman and Krueger 1995; Panayotou 1995; Kahn and Zheng 2016). In our dataset, the sectors with the largest TFP in 2007 are *Processing of Petroleum, Coking, Processing of Nuclear Fuel, Smelting and Pressing of Ferrous Metals* and *Smelting and Pressing of Non-ferrous Metals* while the bottom sectors are *Articles For Culture, Education and Sport Activity, Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products* and *Printing, Reproduction of Recording Media*. TFP grew at an average rate of 1.14% over the period covered, the largest percentage changes being recorded in 2005 at 2%.

We control for variables commonly used in the literature: *sales*, *total asset*, *sales to total asset* and *liabilities to total assets*,<sup>19</sup> which reflect the exposure/access to external creditors. *Sales* and *total asset* control an industry’s size and are computed at the city-industry-year level. *Sales to total assets* measures the efficiency of company in using its assets to generate sales, e.g. revenue.<sup>20</sup> *Liabilities to total assets* refers to the amount of debt relative to the assets owned by a company. A large value indicates a higher leverage capacity since it implies that external creditors finance a large share of the assets. All variables are borrowed from firm-level data, aggregated at the city-industry level, and lagged by one year.

Lastly, the model includes an industry-year fixed effect,  $\gamma_{it}$ , which captures the intrinsic

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<sup>18</sup>We have tested the robustness of all results with the alternative *Levinsohn-Petrin* algorithm, see Levinsohn and Petrin (2003). The results are the same and available on request.

<sup>19</sup>Liabilities to total assets is a leverage ratio, computed by summing current liabilities and non-current liabilities over total assets.

<sup>20</sup>The higher the sales over assets ratio, the more efficient a company is at generating revenue from its assets.

features of each industry within time, such as technological content, subsidies, etc.  $\gamma_{ct}$  is a city-industry fixed effect capturing all industry invariant differences between cities. All variables are in log form and all dependent variables are lagged by one year except  $asset\ tangibility_{cit}$  and  $TFP_{cit}$ . Standard errors are clustered at the city level.

We expect  $\alpha_1$  to be positive and  $\alpha_3$  to be negative, while  $\alpha_2$  and  $\alpha_4$  can be either positive or negative. The availability of internal finance allows firms to choose the type of assets they want to finance, such as R&D or productivity-enhancing assets, potentially including energy-cost saving ones. Investing in intangible assets does not necessarily lead to a decrease in pollution but is possible in the context of China's national policies of incentivizing pollution abatement. The question, therefore, remains an empirical one.

### 2.3.2 Preliminary Evidence

The primary air pollutant  $SO_2$  reached peak emissions in 2005 at 32.41 million tons (see Figure 2.1). Among the 522 cities monitored by the Chinese Ministry of Environment, about 400 had annual average  $SO_2$  levels that meet the Grade II national standard (0.06mg/m<sup>3</sup>),<sup>21</sup> and 33 cities met the worst grade (0.10mg/m<sup>3</sup>). Two years after the 11th Five-Year Plan (FYP) was launched, the situation had slightly changed, according to the Ministry of Environment's annual report on the environment's state.<sup>22</sup> It states that 79% of the audited

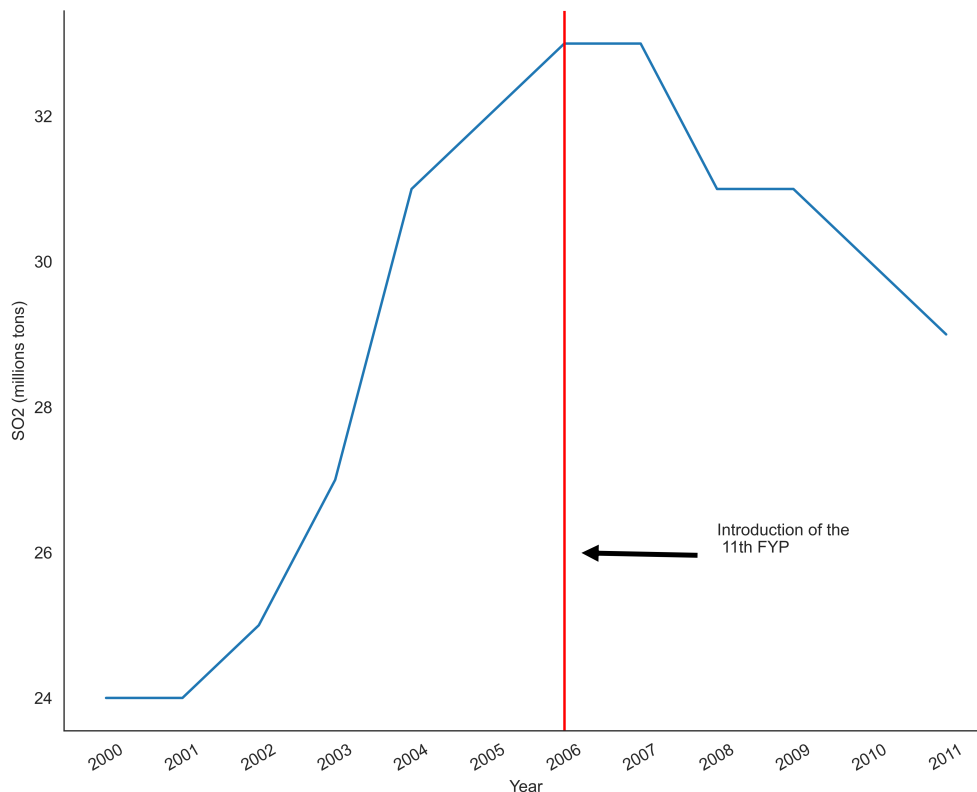
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<sup>21</sup>China uses its own air quality standard, which is less stringent than the WHO's standard. China's National Environmental Monitoring Center (CNEMC) records real-time, hourly air quality data for major cities in China. The real-time data is available at <http://www.cnemc.cn/>. Major air pollutants are monitored, including  $SO_2$ , NO<sub>2</sub>, and PM<sub>10</sub>. To evaluate air quality, the Chinese government applies three classes. Class 1 is for yearly  $SO_2$  levels less than 0.02 mg/m<sup>3</sup>, or a daily average of less than 0.05mg/m<sup>3</sup>. Class 2 is less restrictive. The yearly average should not exceed 0.06 and a daily average of about 0.15. Class 3 is complacent with bad air quality. The yearly average can exceed 0.10 mg/m<sup>3</sup>, and the daily average is 0.25. By contrast, the WHO recommends a daily average of less than 0.02mg/m<sup>3</sup>. For the record, exposure to high  $SO_2$  levels dangerously affects health. According to the WHO, "SO<sub>2</sub> can affect the respiratory system and the functions of the lungs and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis. It makes people more prone to respiratory tract infections".

<sup>22</sup>The report is available at <http://english.mee.gov.cn/Resources/Reports/soe/soe2007/201>.

cities reached Grade II, which is two percentage points higher than in 2005. A towering achievement concerned the Grade III criteria, where less than 1.2% of the cities were above the threshold and represented four percentage points less than in 2005. The most polluted cities are located in Shanxi, Guizhou, Inner Mongolia, and Yunnan provinces.

**Figure 2.1:  $SO_2$  emissions in China from 2000 to 2010**



**Note:** The horizontal red line represents the launch of the 11th Five-Year Plan (FYP). From 2006 onward, China enforced more environmental severity with an optimistic target of a reduction in the emissions of  $SO_2$  by 10% in 2010 as compared with the level in 2005.  
**Source:** The  $SO_2$  emissions data are from the China Statistical Yearbook (2000, 2010)

Chinese policymakers decided to take the environmental issue seriously after the sulfur dioxide ( $SO_2$ ) peak hurt the country in 1995. In no less than 3 years, the officials in Beijing proposed and ratified a law regulating  $SO_2$  emissions. In 1998, the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone policy, referred to as the Two Control Zone (TCZ)

policy, was implemented by the central government to limit the emissions of  $SO_2$ . While the regulation of  $SO_2$  emissions was initially designed to be implemented at the national level, the State Council subsequently chose 175 TCZ cities with very poor environmental records to engage with more effort. Three selection criteria were chosen according to pre-regulation environmental performance. A city was placed under scrutiny if the average annual ambient  $SO_2$  concentration exceeded the national class 2 standard (0.06mg/m<sup>3</sup>), if the daily average ambient  $SO_2$  concentration exceeded the national class3 standard (0.25mg/m<sup>3</sup>), or if the city experienced significant  $SO_2$  emissions.<sup>23</sup> Figure 2.2 shows the aggregated percentage change of  $SO_2$  emissions by the status of the city (TCZ vs no TCZ). On average, cities targeted by the policy managed to maintain or reduce their emissions, especially after 2005.

In this context of a very strong political will to reduce emissions, the question of how companies respond to the incentives they receive is noteworthy. We find at a purely descriptive level that, on the one hand, tangible investments are correlated with the level of pollution (reflecting, in particular, that capital-intensive industries are more polluting), and that, on the other hand, internal finance is negatively correlated with pollution.

We plot the relationship between asset tangibility and  $SO_2$  emissions in figure 2.3. Both axes are in log scale, and each dot represents a city-industry-year level of  $SO_2$  emissions for a given ratio of tangible over total assets. The positive slope indicates that  $SO_2$  emissions is growing positively with the share of tangible over total assets.

In figure 2.4, we plot the two proxies for internal finance against  $SO_2$  emissions. The negative slopes for the log of cash flow (figure 2.4, left-side) and the log of current ratio (figure 2.4, right-side) imply that a larger availability of internal finance leads to lower emissions of

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<sup>23</sup>A city was designated as an acid rain control zone if (1) its average pH value of precipitation was equal to or less than 4.5; (2) its sulfate deposition was above the critical load; (3) its  $SO_2$  emissions were high.

**Figure 2.2: Aggregated percentage change of  $SO_2$  emissions in TCZ and no TCZ cities**



**Note:** The y-axis is the year-to-year percentage change of  $SO_2$  emissions in different locations (TCZ vs No TCZ). **Source:** Authors' own computation.

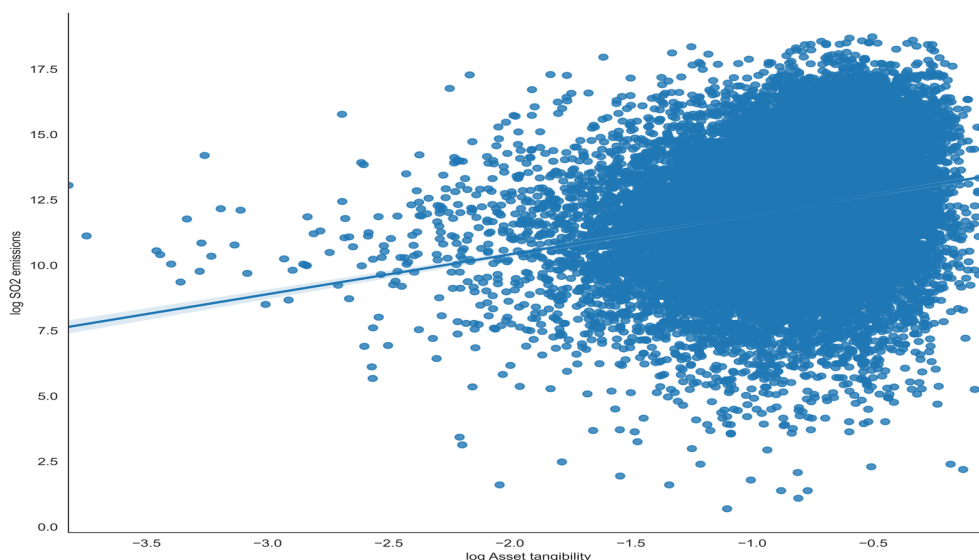
$SO_2$ .

## 2.4 Empirical findings and analysis

Table 2.1 reports equation 2.1 estimation, which depicts the impact of the material nature of investments and the direct impact of the availability of internal finance (cash flow and current ratio) on pollution. In columns 2 and 3,  $SO_2$  removing capacity and  $TFP$  are included. All columns control for the sales, total asset, liabilities to total asset and sales to total asset.



**Figure 2.3: Log asset tangibility against log  $SO_2$  emissions**



**Note:** The x-axis represents the log of tangible assets divided by the total assets, and the y-axis is the log of  $SO_2$  emissions. **Source:** Authors' own computation.

The coefficient on *asset tangibility* is positive and strongly significant at 1% (columns 1 to 3), confirming the assumption that if credit constraints distort the composition of assets towards tangible assets, this favors the emissions of  $SO_2$ .  $SO_2$  increases more than proportionally, by 25%, for each additional 10% increase in *asset tangibility*. The results are similar to Andersen (2017), with an order of magnitude slightly lower by .10 percentage point (.25 versus .35).<sup>24</sup> Furthermore, estimates of *cash flow* and *current ratio* are negative and significant in predicting  $SO_2$  emissions.  $SO_2$  pollution decreases by 4% (resp. by 10%) for each 10% increase in *cash flow* (resp. *current ratio*). This finding suggests that non-tangible investments financed by internal resources benefit the environment and improve the energy efficiency of production.

The coefficient of *TFP* is stable, negative, and significant at 10% (columns 2-3). An increase in *TFP* by 10% reduces  $SO_2$  emissions.  $SO_2$  removing capacity, which captures the

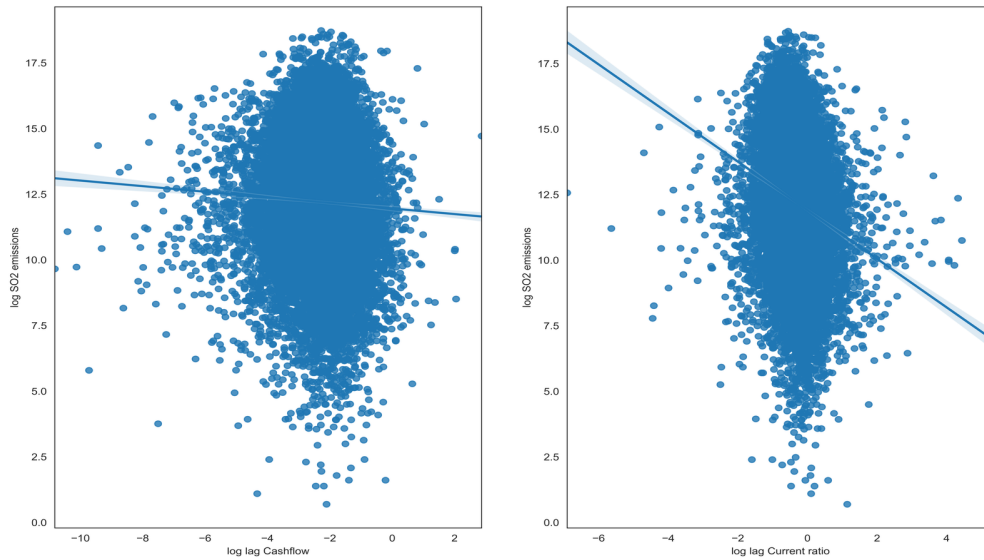
<sup>24</sup>The coefficient in Andersen (2017) comes from Table 5, *Firm-level determinants of aggregate hazard emissions*, column 8, page 204.

**Table 2.1: Determinants of  $SO_2$  emissions**

|                           | Dependent variable: $SO_2$ emissions in log |                     |                      |
|---------------------------|---|---------------------|----------------------|
|                           | (1)   | (2)                 | (3)                  |
| log(asset tangibility)    | 0.246***<br>(0.045)                         | 0.275***<br>(0.045) | 0.243***<br>(0.045)  |
| <i>Internal finance</i>   |   |                     |                      |
| log(cashflow)             | -0.045***<br>(0.017)                        |                     | -0.044***<br>(0.017) |
| log(current ratio)        | -0.098***<br>(0.028)                        |                     | -0.101***<br>(0.028) |
| $SO_2$ removing capacity  |   | -0.011*<br>(0.006)  | -0.011**<br>(0.005)  |
| log(TFP)                  |   | -0.666*<br>(0.371)  | -0.693*<br>(0.371)   |
| <i>Control variables</i>  |   |                     |                      |
| log(sales)                | 0.371***<br>(0.032)                         | 0.389***<br>(0.032) | 0.386***<br>(0.033)  |
| log(total asset)          | 0.227***<br>(0.031)                         | 0.221***<br>(0.031) | 0.224***<br>(0.031)  |
| log(liabilities to asset) | -0.021<br>(0.056)                           | 0.077<br>(0.050)    | -0.021<br>(0.056)    |
| log(sales to asset)       | 0.028<br>(0.029)                            | -0.019<br>(0.025)   | 0.031<br>(0.029)     |
| industry-year             | Yes   | Yes                 | Yes                  |
| city-year                 | Yes   | Yes                 | Yes                  |
| Observations              | 24,383                                      | 24,383              | 24,383               |
| R <sup>2</sup>            | 0.627                                       | 0.627               | 0.628                |

This table reports estimates of equation 2.1. *Asset tangibility* denotes tangible assets over total assets. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *SO<sub>2</sub> removing capacity* is the capacity to remove  $SO_2$  emissions per hour divided by sales. *TFP* stands for Total Factor Productivity and is estimated using the Olley and Pake algorithm. The following variables are lagged by one-year: *current ratio*, *cash flow*, and all the control variables. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Figure 2.4: Log internal finance against log  $SO_2$  emissions**



**Note:** The x-axis represents the log of cash flow (left side) and log of current ratio (right side) and the y-axis is the log of  $SO_2$  emissions. **Source:** Authors' own computation.

efficiency of an industry to remove pollution, is significant at 10%. For each 10% increase in the pollution abatement efficiency, the city-industry can reduce  $SO_2$  emissions by 1%. The inclusion of the control variables does not alter the main findings.

We have provided evidence of an average effect of financial reliance on the emissions of  $SO_2$ . We investigate now whether or not this average effect differs across sectors, types of ownership, and industrial policies.

We look to see if the  $SO_2$ -asset tangibility,  $SO_2$ -internal cash availability, and  $SO_2$ -TFP elasticity differ when firms produce in industries emitting a relatively large amount of pollution. In table 2.2, we divide the industries into two categories: polluted and less polluted. To construct the categories, we aggregate the  $SO_2$  emissions by industry-year and compute the third decile value. All industries located above the threshold are designated as polluted. Column 1 confirms that the previous findings hold across polluted vs non polluted industries, and that the magnitude of the coefficient *asset tangibility* is larger for firms

in polluted industries than for less polluted ones (.22 *versus* .19). *Cash flow* in polluted sectors does not influence  $SO_2$  emissions, while *current ratio* does. For industries under the threshold and considered less polluted, *cash flow* availability plays a significant role in reducing pollution.<sup>25</sup>

The economic literature has extensively documented the effects of a firm's ownership on several economic outcomes, among others (Héricourt and Poncet 2009; Poncet et al. 2010; Li et al. 2018). Some articles in this literature deal more specifically with environmental performance. A theoretical framework is provided by Wood (2013), who studies the effects of financial assistance programs, commonly known as bailouts, on pollution. The paper develops a partial equilibrium model of the firm to capture the effect of bailouts on firms' emission decisions, which indicates that the expectation of bailouts increases ex-ante emissions. Several empirical papers support this model's prediction. Peszko and Żylicz\* (1998) consider European countries in transition and observe that the demand for environmental financing can be affected both by environmental policy measures (such as internalization of externalities) and by other factors, such as the softness of budget constraints faced by firms, which refers to the firms' ownerships. Wang and Jin (2007) explores the differences in water pollution control performance of Chinese industries with different types of ownership – State-owned (SOE), collectively or community owned (COE), and privately owned (POE). Maurel and Pernet (2020) demonstrate that the environmental performance of SOEs is undermined by the soft budget constrain they face. We investigate the heterogeneity of the impact of asset tangibility, internal finance availability, and TFP on  $SO_2$  emissions stemming from ownership by distinguishing cities dominated by either state-owned or private enterprises (respectively foreign *versus* domestic). This distinction between environments more

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<sup>25</sup>The most polluted sectors are as follows: Textile Paper, Coking, Raw Chemical Materials, Non-metallic Products, Smelting ferrous Metals and Smelting Non-ferrous Metals. Similar results hold when we change the threshold to a higher decile (.8 to .95).

**Table 2.2: Polluted versus less polluted sectors**

|                           | Dependent variable: $SO_2$ emissions in log |                      |
|---------------------------|---|----------------------|
|                           | (1)   | (2)                  |
|                           | Above                                       | Below                |
| log(asset tangibility)    | 0.218**<br>(0.085)                          | 0.188***<br>(0.055)  |
| <i>Internal finance</i>   |   |                      |
| log(cashflow)             | -0.013<br>(0.037)                           | -0.076***<br>(0.019) |
| log(current ratio)        | -0.153***<br>(0.055)                        | -0.043<br>(0.035)    |
| $SO_2$ removing capacity  | -0.008**<br>(0.003)                         | 0.428**<br>(0.190)   |
| log(TFP)                  | -2.968***<br>(0.700)                        | 0.537<br>(0.462)     |
| <i>Control variables</i>  |   |                      |
| log(sales)                | 0.693***<br>(0.065)                         | 0.256***<br>(0.037)  |
| log(total asset)          | 0.069<br>(0.058)                            | 0.254***<br>(0.037)  |
| log(liabilities to asset) | -0.162<br>(0.127)                           | 0.072<br>(0.064)     |
| log(sales to asset)       | -0.007<br>(0.064)                           | 0.051<br>(0.035)     |
| industry-year             | Yes   | Yes                  |
| city-year                 | Yes   | Yes                  |
| Observations              | 8,451                                       | 15,932               |
| R <sup>2</sup>            | 0.626                                       | 0.475                |

*Asset tangibility* denotes tangible assets over total assets. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *SO<sub>2</sub> removing capacity* is the capacity to remove  $SO_2$  emissions per hour divided by sales. *TFP* stands for Total Factor Productivity and is estimated using the Olley and Pake algorithm. The following variables are lagged by one-year: *current ratio*, *cash flow*, and all the control variables. All industries with a total  $SO_2$  emission above the third decile value are classified as "Above" and designated as polluted industries, otherwise "Below." Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

or less exposed to the soft budget constraints enables us to validate that the mechanism at work in the domestic finance/pollution nexus is the incentive to invest in environmentally friendly assets, to which the private sector is more likely to respond. We expect, therefore, a smaller and even non-significant coefficient for those cities.

To test the prediction, we use the firms' ownership information in the annual surveys of Chinese manufacturing firms dataset to construct a list of cities dominated by SOEs (foreign firms). We compute SOEs (foreign firms) total sectorial output for each city using 2002 as a baseline year. We then split the sample into two sub-samples: SOEs (foreign firms) dominated sub-sample refers to cities where the total sectorial output of SOEs (foreign firms) is strictly above the total sectorial output of private (domestic) firms. The non-SOEs (domestic firms) sub-sample includes the remaining cities. We use different thresholds for splitting the sample by taking SOE sectorial output higher than 30%, 40%, 50% of total sectorial output. Our conclusions are robust. They hold as well if one takes employment instead of sectorial output.<sup>26</sup>

Columns 1 and 3 indicate that both *asset tangibility* and internal finance (*cash flow* and *current ratio*) do not affect the emissions of  $SO_2$  in cities where the production stems mostly from SOEs. By contrast, in cities dominated by the private sector, *asset tangibility* and internal finance pollution elasticity are significant with the expected signs (columns 2 and 4). This is consistent with a recent paper, Maurel and Pernet (2020), which shows that cities with smaller shares of SOEs have been more sensitive to the new environmental target and have reduced their emissions of pollutants significantly. Cities dominated by SOEs have not taken similar steps. In a similar vein, Larsen and Oehler (2022) indicates that Chinese renewable energy companies are at a financing disadvantage compared to conventional energy

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<sup>26</sup>Table 2.9 in the appendix

**Table 2.3:  $SO_2$  emissions and city ownership**

|                          |     | Dependent variable: $SO_2$ emissions in log |                      |                   |                      |                      |                      |                      |                      |
|--------------------------|-----|---|----------------------|-------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|                          |     | (1)   | (2)                  | (3)               | (4)                  | (5)                  | (6)                  | (7)                  | (8)                  |
|                          |     | SOE   | Private              | SOE               | Private              | Foreign              | Domestic             | Foreign              | Domestic             |
| log(asset tangibility)   |     | 0.206<br>(0.182)                            | 0.240***<br>(0.047)  | 0.211<br>(0.182)  | 0.237***<br>(0.047)  | 0.191<br>(0.186)     | 0.247***<br>(0.047)  | 0.191<br>(0.185)     | 0.242***<br>(0.047)  |
| log(cashflow)            |     | 0.038<br>(0.073)                            | -0.047***<br>(0.018) | 0.038<br>(0.073)  | -0.047***<br>(0.018) | -0.093*<br>(0.054)   | -0.041**<br>(0.018)  | -0.093*<br>(0.054)   | -0.041**<br>(0.018)  |
| log(current ratio)       |     | -0.014<br>(0.108)                           | -0.105***<br>(0.030) | -0.012<br>(0.108) | -0.107***<br>(0.030) | -0.129<br>(0.098)    | -0.093***<br>(0.031) | -0.128<br>(0.097)    | -0.096***<br>(0.031) |
| $SO_2$ removing capacity |     | 1.140<br>(1.182)                            | -0.010*<br>(0.005)   | 1.135<br>(1.171)  | -0.010**<br>(0.005)  | 20.327***<br>(2.917) | -0.011**<br>(0.005)  | 20.326***<br>(2.916) | -0.012**<br>(0.005)  |
| log(TFP)                 |     |   |                      | 0.512<br>(1.068)  | -0.741*<br>(0.418)   |                      |                      | 0.047<br>(1.390)     | -0.926**<br>(0.381)  |
| Observations             |     | 2,996                                       | 21,387               | 2,996             | 21,387               | 3,289                | 21,094               | 3,289                | 21,094               |
| R <sup>2</sup>           |     | 0.817                                       | 0.630                | 0.817             | 0.630                | 0.718                | 0.642                | 0.718                | 0.642                |
| log(asset tangibility)   |     | 0.125<br>(0.158)                            | 0.241***<br>(0.047)  | 0.122<br>(0.157)  | 0.239***<br>(0.047)  | 0.189<br>(0.166)     | 0.250***<br>(0.048)  | 0.189<br>(0.166)     | 0.246***<br>(0.048)  |
| log(cashflow)            |     | 0.048<br>(0.050)                            | -0.053***<br>(0.019) | 0.047<br>(0.050)  | -0.053***<br>(0.019) | -0.064<br>(0.047)    | -0.042**<br>(0.019)  | -0.064<br>(0.047)    | -0.042**<br>(0.019)  |
| log(current ratio)       |     | 0.005<br>(0.090)                            | -0.117***<br>(0.031) | 0.001<br>(0.089)  | -0.119***<br>(0.031) | -0.159*<br>(0.082)   | -0.093***<br>(0.031) | -0.159*<br>(0.082)   | -0.095***<br>(0.031) |
| $SO_2$ removing capacity |     | 1.249<br>(0.875)                            | -0.011**<br>(0.005)  | 1.264<br>(0.880)  | -0.011**<br>(0.005)  | 14.977***<br>(3.960) | -0.012**<br>(0.005)  | 14.977***<br>(3.960) | -0.012**<br>(0.005)  |
| log(TFP)                 |     |   |                      | -0.857<br>(0.944) | -0.621<br>(0.431)    |                      |                      | -0.019<br>(1.145)    | -0.878**<br>(0.378)  |
| Observations             |     | 3,978                                       | 20,405               | 3,978             | 20,405               | 4,181                | 20,202               | 4,181                | 20,202               |
| R <sup>2</sup>           |     | 0.791                                       | 0.627                | 0.791             | 0.627                | 0.698                | 0.645                | 0.698                | 0.645                |
| log(asset tangibility)   |     | 0.173<br>(0.116)                            | 0.254***<br>(0.050)  | 0.170<br>(0.116)  | 0.251***<br>(0.050)  | 0.077<br>(0.141)     | 0.259***<br>(0.051)  | 0.076<br>(0.141)     | 0.253***<br>(0.051)  |
| log(cashflow)            |     | 0.055<br>(0.043)                            | -0.056***<br>(0.019) | 0.055<br>(0.043)  | -0.055***<br>(0.019) | -0.058<br>(0.042)    | -0.038*<br>(0.020)   | -0.058<br>(0.043)    | -0.038*<br>(0.019)   |
| log(current ratio)       |     | -0.060<br>(0.075)                           | -0.104***<br>(0.033) | -0.061<br>(0.075) | -0.106***<br>(0.033) | -0.131*<br>(0.069)   | -0.088***<br>(0.031) | -0.129*<br>(0.069)   | -0.091***<br>(0.031) |
| $SO_2$ removing capacity |     | 1.296<br>(0.925)                            | -0.009*<br>(0.005)   | 1.303<br>(0.929)  | -0.009*<br>(0.005)   | 8.040***<br>(2.641)  | -0.011**<br>(0.005)  | 8.040***<br>(2.640)  | -0.012**<br>(0.005)  |
| log(TFP)                 |     |   |                      | -0.751<br>(0.822) | -0.548<br>(0.455)    |                      |                      | 0.443<br>(1.065)     | -0.916**<br>(0.382)  |
| Observations             |     | 5,247                                       | 19,136               | 5,247             | 19,136               | 5,356                | 19,027               | 5,356                | 19,027               |
| R <sup>2</sup>           |     | 0.755                                       | 0.628                | 0.755             | 0.628                | 0.676                | 0.650                | 0.676                | 0.650                |
| industry-year            | Yes | Yes   | Yes                  | Yes               | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| city-year                | Yes | Yes   | Yes                  | Yes               | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |

*Asset tangibility* denotes tangible assets over total assets. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *SO<sub>2</sub> removing capacity* is the capacity to remove  $SO_2$  emissions per hour divided by sales. *TFP* stands for Total Factor Productivity and is estimated using the Olley and Pake algorithm. A city is considered as being dominated by SOEs (foreign firms) if the total industrial output of SOEs (foreign firms) over the total industrial output exceeds a threshold within a city. All columns control for *total asset*, *liabilities/assets*, and *sales/assets*. The following variables are lagged by one-year: *current ratio*, *cash flow*, and all the control variables. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

companies. The underlying reason is that the latter are largely state-owned, while renewable companies are largely private. Yet the Chinese financial system has a strong preference for state-owned enterprises.<sup>27</sup> In columns 3 and 4, we show that an increase in *TFP* in a city dominated by the state sector does not affect the  $SO_2$  emissions, while in a private-dominated city it does. This suggests that credit to private firms in China not only fueled economic growth, but also managed to reduce pollution to some extent.

There is a large piece of literature on external borrowing, which documents the difference in credit access between domestic firms and foreign firms (Jarreau and Poncet 2014; Manova et al. 2015; Poncet et al. 2010). Foreign-owned companies are not rationed in their access to credit in China because they can use their parent company funds and raise money on the capital market. We seek to determine whether this easier access to credit for foreign enterprises is reflected in our results. Columns 5 and 7 reflect the results for foreign-dominated cities, and columns 6 and 8 for domestic-dominated cities. As expected, the coefficient of *asset tangibility* is positive but statistically insignificant for foreign-dominated cities, and it remained negative and large for domestic-dominated cities.

Finally, we test the effectiveness of internal finance and TFP on  $SO_2$  emissions when cities face different environmental and industrial policies. In 1998, the government designed 175 cities<sup>28</sup> with poor environmental performances. For these cities, the Two Control Zones (TCZ) policy's primary objective was to reduce the emissions of  $SO_2$ . Emissions controls have also been incorporated in the 10th and 11th FYP to work in cooperation with the TCZ policy. TCZ cities were assigned a more stringent reduction target than other cities. Table

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<sup>27</sup>It is well-established in the literature that China's political pecking order of firms is enforced through the systematic misallocation of financial resources (Dollar and Wei 2007) and that credit allocation is biased in favor of state-owned enterprises (Brandt and Li 2003; Hale and Long 2011; Huang 2003). State-owned banks typically provide loans to SOEs without considering their profitability and default risk (Bai et al. 2006; Boyreau-Debray 2003). The relatively cheap inflow of credit to SOEs has not allowed them not increase their TFP (Li et al. 2018).

<sup>28</sup>The areas cover 11.4% of China's surface and contain sources responsible for 60% of total  $SO_2$  emissions in 1998.



2.4 uses the list of TCZ cities to split our dataset into two groups: cities targeted by the TCZ policy, and those not.<sup>29</sup> Results are available in columns 1 and 2. The  $SO_2$  - asset tangibility elasticity is slightly larger for non-TCZ cities (.23 *versus* .25), but the difference is not significant. This interesting result calls for the following interpretation: firms operating in TCZ cities are asked to install pollution control equipment and other expensive equipment to keep their operating license. Smaller and more inefficient firms have to shut down, and only the most productive and largest firms can stay in business.<sup>30</sup> Several empirical studies show that large companies have easier access to external financing and generate more cash flow. Facing fewer constraints and being selected, large firms in TCZ cities with more tangible assets are greener. Besides, as expected, the *TFP* estimate is negative and significant. Low productive firms have to leave the market because they cannot upgrade their equipment, while the remaining firms, using more sophisticated capital, improve TFP and reduce their  $SO_2$  emissions.

Columns 3 and 4 focus on the growth-driven policy called, Special Policy Zone policy. It aims at boosting the attractiveness of SPZ cities for foreign firms, exporters, or high-tech firms, which benefit from lower taxes and access to cheaper credit or subsidies, among other advantages (Hering and Poncet 2014; Wang and Wei 2008). Cities focusing on growth (SPZ) generate more cash flow, but this has no impact on their emissions of  $SO_2$ . Similar results hold for *TFP* (column 7). They illustrate that productivity gains do not automatically translate into a decline in pollution, unless they are based on an explicit pollution control strategy.

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<sup>29</sup>Table 2.16 in the appendix provides the list of TCZ cities present in our dataset.

<sup>30</sup>The example of the mining industry illustrates this selection bias very well. Among the strategies at the disposal of the Chinese authorities, a common one is to close down coal mines, especially small power stations with a capacity less than 50,000 KW (kilowatt). For instance, in 2002, 338 small power units, 784 product lines in small cement and glass plants, 404 lines in iron and steel plants, and 1422 additional pollution sources were closed. Source: <https://www.annualreviews.org/doi/abs/10.1146/annurev.energy.27.122001.083421>.

**Table 2.4: TCZ and SPZ versus no TCZ and no SPZ**

|                           | Dependent variable: $SO_2$ emissions in log |                      |                      |                     |
|---------------------------|---|----------------------|----------------------|---------------------|
|                           | (1)   | (2)                  | (3)                  | (4)                 |
|                           | TCZ   | No TCZ               | SPZ                  | No SPZ              |
| log(asset tangibility)    | 0.228***<br>(0.060)                         | 0.244***<br>(0.064)  | 0.205**<br>(0.095)   | 0.229***<br>(0.050) |
| <i>Internal finance</i>   |   |                      |                      |                     |
| log(cashflow)             | -0.044**<br>(0.022)                         | -0.050*<br>(0.027)   | -0.070**<br>(0.030)  | -0.032<br>(0.020)   |
| log(current ratio)        | -0.133***                                   | -0.043               | -0.148**             | -0.076**            |
| $SO_2$ removing capacity  | 0.637**<br>(0.313)                          | -0.014***<br>(0.005) | -0.015***<br>(0.004) | 0.066<br>(0.160)    |
| log(TFP)                  | -1.005*<br>(0.527)                          | -0.236<br>(0.491)    | 0.222<br>(0.826)     | -0.905**<br>(0.407) |
| <i>Control variables</i>  |   |                      |                      |                     |
| log(sales)                | 0.380***<br>(0.045)                         | 0.397***<br>(0.049)  | 0.335***<br>(0.074)  | 0.412***<br>(0.036) |
| log(total asset)          | 0.259***<br>(0.043)                         | 0.178***<br>(0.043)  | 0.311***<br>(0.073)  | 0.193***<br>(0.033) |
| log(liabilities to asset) | -0.054<br>(0.081)                           | 0.044<br>(0.071)     | 0.058<br>(0.108)     | -0.043<br>(0.064)   |
| log(sales to asset)       | 0.019<br>(0.041)                            | 0.045<br>(0.042)     | 0.061<br>(0.061)     | 0.020<br>(0.033)    |
| industry-year             | Yes   | Yes                  | Yes                  | Yes                 |
| city-year                 | Yes   | Yes                  | Yes                  | Yes                 |
| Observations              | 15,175                                      | 9,208                | 8,147                | 16,236              |
| R <sup>2</sup>            | 0.634                                       | 0.633                | 0.631                | 0.636               |

*Asset tangibility* denotes tangible assets over total assets. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *SO<sub>2</sub> removing capacity* is the capacity to remove  $SO_2$  emissions per hour divided by sales. *TFP* stands for Total Factor Productivity and is estimated using the Olley and Pake algorithm. The following variables are lagged by one-year: *current ratio*, *cash flow*, and all the control variables. TCZ are cities targeted by the government with very poor environmental performance. The list of TCZ is provided by the State Council, 1998. "Official Reply to the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas". SPZ cities refer to city located in high-technology industry development areas, economic and technological development areas, and export processing zones. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

To sum up, the city-targeted environmental policy is beneficial for reducing  $SO_2$  emissions through a larger availability of internal financing and better productivity. Firms operating in those cities generate enough cash flow to comply with the burdensome requirement to secure licenses and purchase pollution abatement equipment. However, the growth-oriented policy does not interfere with  $SO_2$  emissions. The productivity gains from a better market environment (tax freedom and cheaper credit), are irrelevant to reducing pollution. These results are in line with Maurel and Pernet (2020).

## 2.5 Mechanisms

We now explore the individual (firm-level) dimension of our dataset to investigate the mechanisms by which our variables of interest influence pollution. We are paying a special attention to the financial structure of firms, especially to the availability of internal financing and the intensity of financial constraints. Our theoretical approach is summarised in Table 2.5. Overall, both access to bank credit and availability of internal finance can be expected to favour R&D, technical progress (column 3) and investment in pollution abatement equipment (column 4). We emphasize the availability of internal finance, which is likely to reduce the share of tangible assets (column 2) and makes investment in intangible assets (including R&D and pollution abatement equipment) more likely. All of these mechanisms examined at the firm level have the potential to reduce the emission of pollutants, as shown in the previous section. They are tested one by one below.

**Table 2.5: Transmission channels**

| Equation/Table   | $SO_2$ emissions               | Tangible assets                 | TFP                    | Equipment (to remove $SO_2$ emissions) |
|--|--------------------------------|---------------------------------|------------------------|--|
| Asset tangibility  | 2.1/2.1, 2.2, 2.3, 2.4 and 2.7 | 2.2 and 2.3/ 2.6, 2.11 and 2.12 | 2.4/2.7, 2.14 and 2.15 | 2.5/2.8                                |
| Internal finance   | +                              |                                 |                        |  |
| cashflow   | +/-                            | -                               | +                      | +                                      |
| current ratio  | +/-                            | -                               | +                      | +                                      |
| $SO_2$ removing capacity (capacity to remove $SO_2$ emissions) | -                              |                                 |                        |  |
| TFP  | -                              |                                 |                        |  |
| External finance   |                                |                                 |                        |  |
| credit's supply  |                                | +                               | +                      | +/-                                    |

**Note:** Tangible assets is proxy by asset tangibility over total assets, or Research and Development over total assets. TFP stands for Total Factor Productivity, and is estimated using the Olley and Pake algorithm. Equipment is the number of  $SO_2$  removal equipment installed.  $SO_2$  removing capacity is the capacity to remove  $SO_2$  emissions per hour divided by sales. *Asset tangibility* denotes tangible assets over total assets. Internal finance represents all flows of money generated by a firm. It is usually proxied by *cash flow* (net income + depreciation over assets) or *current ratio* (current assets divided by current liabilities). External finance represents all funds that firms obtain from outside banks or shareholders. It is proxied by *credit supply* (all credit or long-term credit to GDP ratio).

### 2.5.1 Internal finance and investment in tangible *versus* intangible assets

A growing literature analyzes the extent to which the availability of internal sources of financing affects the firms' investments in fixed assets, inventory, or R&D (Chen and Guariglia 2013; Fazzari et al. 2000; Rajan and Zingales 1998). According to this literature, firms with more internal finance are less likely to invest in tangible assets, and more likely to use their cash flow to fund technological innovations and R&D. From the supply side, banks are reluctant to finance intangible assets, because the latter are not considered as valuable collateral (Brown and Petersen 2009).<sup>31</sup> The biases that stem from this preference of banks for tangible assets, and from investments in R&D and intangible assets to be handled by internal finance, result in more or less pollution, as shown in the previous section. We now examine the financial determinants of these variables at the firm level.

<sup>31</sup>Collateral is behind the scarcity of loans to finance innovative activities, but is not the only reason. The literature mentions two additional factors: informational asymmetry and moral hazard (Brown et al. 2013; Hall and Lerner 2010).

Equations 2.2 and 2.3 embed this literature. Equation 2.2 hypothesizes that assets composition (tangible *versus* intangible) is affected by internal finance availability proxy by *cash flow* and *current ratio*. Equation 2.3 expresses that productivity-enhancing activities such as R&D, and the adoption of new technology, depend primarily on the firm's internal finance availability. We expect the relationships to be weaker for SOEs and foreign firms. As for the former, banks are more likely to provide SOEs with the credit they need, whatever the degree of the tangibility of their assets, while foreign firms enjoy easier access to finance. We check that our estimates reflect this firm's heterogeneity and differ in magnitude across the different ownership statuses.

$$\begin{aligned} \text{asset tangibility}_{fct} = & \beta_1 \text{cash flow}_{fct} + \beta_2 \text{current ratio}_{fct} + \beta_3 \text{external finance}_{pt} + \\ & \beta_5 X_{fct} + \zeta_f + \gamma_i + \gamma_t + \epsilon_{fct} \end{aligned} \quad (2.2)$$

$$\begin{aligned} \text{R\&D}_{fct} = & \beta_1 \text{cash flow}_{fct} + \beta_2 \text{current ratio}_{fct} + \beta_3 \text{external finance}_{pt} + \\ & \beta_5 X_{fct} + \zeta_f + \gamma_i + \gamma_t + \epsilon_{fct} \end{aligned} \quad (2.3)$$

Where *asset tangibility*<sub>fct</sub> in equation 2.2 refers to the share of asset tangibility over total assets, and *R&D*<sub>fct</sub> in equation 2.3 represents the share of research expenditure over total asset. We use *cash flow*<sub>fit</sub> and *current ratio*<sub>fit</sub> as a proxy for internal finance following the methodology explained in section 2.3.2. Analyses can be done at firm-level, *f*, city *c*, industry *i* and year *t*, as all data are available at this thin level. We also add separately, two variables that capture the availability of external finance at the province-level, *p*, over the year *t*, namely the share of total credit over the province GDP and the share of long term credit over the province GDP.<sup>32</sup> *X*<sub>fct</sub> includes usual controls found in the literature,

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<sup>32</sup>Both measures are computed using the bank loan to GDP ratio by province from 2001 to 2007, from the Almanac of China's Finance and Banking 2007.

namely *liabilities to assets*, *age* and *export to sale*. The inclusion of industry and time ( $\gamma_i$ ,  $\gamma_t$ ) fixed effects remove the trends associated with all firms in a particular industry. Finally, entering firm fixed effects ( $\zeta_f$ ) removes all unobserved factors contributing to a firm's assets accumulation within a city.

**Table 2.6: Asset tangibility versus R&D and internal finance**

|                           | Dependent variables: asset tangibility and R&D |                       |                      |                       |                      |                       |
|---------------------------|--|-----------------------|----------------------|-----------------------|----------------------|-----------------------|
|                           | (1)  | (2)                   | (3)                  | (4)                   | (5)                  | (6)                   |
|                           | asset tangibility                              | RD                    | asset tangibility    | RD                    | asset tangibility    | RD                    |
| log(cashflow)             | -0.149***<br>(0.002)                           | 0.0003***<br>(0.0001) | -0.150***<br>(0.002) | 0.0003***<br>(0.0001) | -0.149***<br>(0.002) | 0.0003***<br>(0.0001) |
| log(current ratio)        | -0.024***<br>(0.002)                           | 0.0001*<br>(0.0001)   | -0.024***<br>(0.002) | 0.0001*<br>(0.0001)   | -0.024***<br>(0.002) | 0.0001*<br>(0.0001)   |
| log(liabilities to asset) | -0.040***<br>(0.004)                           | 0.0004***<br>(0.0002) | -0.040***<br>(0.004) | 0.0004**<br>(0.0002)  | -0.040***<br>(0.004) | 0.0004***<br>(0.0002) |
| log(age)                  | 0.019***<br>(0.002)                            | 0.00004<br>(0.0004)   | 0.019***<br>(0.002)  | 0.00004<br>(0.0004)   | 0.019***<br>(0.002)  | 0.00004<br>(0.0004)   |
| export to sale            | -0.001<br>(0.006)                              | 0.0002<br>(0.0002)    | -0.001<br>(0.006)    | 0.0002<br>(0.0002)    | -0.001<br>(0.006)    | 0.0002<br>(0.0002)    |
| all credit                |  |                       | 0.106***<br>(0.010)  | -0.005***<br>(0.002)  |                      |                       |
| long term credit          |  |                       |                      |                       | 0.010***<br>(0.003)  | -0.001<br>(0.001)     |
| firm                      | Yes  | Yes                   | Yes                  | Yes                   | Yes                  | Yes                   |
| industry                  | Yes  | Yes                   | Yes                  | Yes                   | Yes                  | Yes                   |
| year                      | Yes  | Yes                   | Yes                  | Yes                   | Yes                  | Yes                   |
| Observations              | 402,287  | 152,673               | 402,287              | 152,673               | 402,287              | 152,673               |
| R <sup>2</sup>            | 0.878  | 0.669                 | 0.878                | 0.669                 | 0.878                | 0.669                 |

This table reports estimates of equations 2.2 and 2.3. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities.; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province-level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm-level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

Table 2.6 reports estimates of equation 2.2 in column 1, and estimates of equation 2.3 in column 2. For the latter, information is available only from 2005 to 2007,<sup>33</sup> implying a lower number of observations. The results validate the assumption that the availability of

<sup>33</sup>Firms started to report R&D expenditure in 2005. In our dataset, 20% of the firms declared spending money on R&D, which kept increasing over time, from 19% in 2005 to 22% in 2007.

internal finance distorts the allocation of assets within firms. Specifically, the elasticity of *asset tangibility* with respect to *cash flow* is -0.149, and its elasticity with respect to *current ratio* is -0.024 (column 1). Column 2 also reports a positive association between *cash flow* and *R&D*, implying that Chinese firms use their internal finances to invest in innovative projects. Columns 3 to 6 extend the model by including variables reflecting the availability of external finance, namely *all credit* and *long term credit*. The coefficients on those two variables are positive and significant, suggesting that banks tend to mostly finance tangible assets. At the same time, they are negative for the R&D equation, confirming that banks are not inclined to finance innovation (Brown et al. 2013; Hall and Lerner 2010; Liu et al. 2022).

Tables 2.10, 2.11 and 2.12 in the appendix display the estimates obtained when equations 2.2 and 2.3 include a dummy *credit constrained* for credit-constrained *versus* non-constrained firms, *private* for private firms *versus* SOEs, and *domestic* for foreign firms *versus* domestic firms.<sup>34</sup> Columns 1 and 2 interact cash flow and current ratio with a dummy *credit constrained* set equal to 1 when the firm is credit-constrained (table 2.10), when it belongs to private owners (table 2.11) and finally when the firm is domestic (table 2.12)). Columns 3 and 4 include *all credit* while columns 5 and 6 add *long term credit*. As expected, the estimates are bigger in magnitude and negative for constrained firms. They are smaller for SOEs and foreign firms, which face less constraints in their access to funding. Therefore, they are less sensitive to the availability of internal finance to invest in either tangible asset or R&D.

## 2.5.2 Internal finance and TFP

The environmental literature has documented the decrease in polluting emissions induced by TFP, which means that more productive firms are more resource efficient (Brown and

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<sup>34</sup>In our dataset, a firm does not change ownership over time, but can change the location of its plant.

Petersen 2009; Fazzari et al. 1988; Li et al. 2018). According to table 2.5 and the previous section results, this is also true for China, as higher TFP reduces pollutant emissions. This section examines to which extent internal funding plays a role by being used to fund technology improvements and higher TFP.

We estimate the following equation at the firm-level:

$$\begin{aligned} \text{TFP}_{fct} = & \beta_1 \text{cash flow}_{fit} + \beta_2 \text{current ratio}_{fit} + \beta_3 \text{external finance}_{pt} + \\ & \beta_5 X_{fct} + \zeta_f + \gamma_i + \gamma_t + \epsilon_{fct} \end{aligned} \quad (2.4)$$

where the dependent variable  $TFP_{fct}$  is the productivity of firm  $f$  computed with the Olley–Pakes algorithm at the firm-city-industry-time level, as explained in the data section. We use  $\text{cash flow}_{fit}$  and  $\text{current ratio}_{fit}$  as proxies for internal finance. We also evaluate the possibility of using external financing by adding total and long-term credit over GDP, calculated at the province level  $p$  during 2001 to 2007.<sup>35</sup>  $X_{fct}$  refers to all other firm-level controls, including firm’s *liabilities to asset*, *asset tangibility*, *labor to capital*, *total asset*, *age*, and *export to sale*. The inclusion of industry and time ( $\gamma_i$ ,  $\gamma_t$ ) fixed effects removes the trends associated with all firms in a particular industry. Finally, entering firms’ fixed effects ( $\zeta_f$ ) removes all unobserved factors contributing to a firm’s TFP within a city.

Table 2.7 reports the estimates of equation 2.4. Column 1 is the baseline specification, and columns 2 and 3 add external finance availability. In all specifications, the coefficient estimates for *cash flow* and *current ratio*, have the expected signs and are significant at 1%. For instance in column 1, the elasticity of  $TFP$  with respect to *cash flow* is .018, and

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<sup>35</sup>Credit supply is measured by taking the average bank loan to GDP ratio by province (2001–2007). The data sources come from the Almanac of China’s Finance and Banking, 2007.



**Table 2.7: Internal/external finance and TFP**

|                           | Dependent variable: TFP in log |                      |                      |
|---------------------------|--------------------------------|----------------------|----------------------|
|                           | (1)                            | (2)                  | (3)                  |
| log(cashflow)             | 0.018***<br>(0.0002)           | 0.018***<br>(0.0002) | 0.018***<br>(0.0002) |
| log(current ratio)        | 0.002***<br>(0.0002)           | 0.002***<br>(0.0002) | 0.002***<br>(0.0002) |
| log(liabilities to asset) | 0.008***<br>(0.0004)           | 0.008***<br>(0.0004) | 0.008***<br>(0.0004) |
| log(asset tangibility)    | 0.043***<br>(0.001)            | 0.042***<br>(0.001)  | 0.043***<br>(0.001)  |
| log(labor to capital)     | 0.026***<br>(0.0005)           | 0.026***<br>(0.0005) | 0.026***<br>(0.0005) |
| log(total asset)          | 0.065***<br>(0.001)            | 0.065***<br>(0.001)  | 0.065***<br>(0.001)  |
| log(age)                  | 0.004***<br>(0.0003)           | 0.004***<br>(0.0003) | 0.004***<br>(0.0003) |
| export to sale            | 0.008***<br>(0.002)            | 0.008***<br>(0.002)  | 0.008***<br>(0.002)  |
| all credit                |                                | 0.023***<br>(0.001)  |                      |
| long term credit          |                                |                      | 0.003***<br>(0.0003) |
| firm                      | Yes                            | Yes                  | Yes                  |
| industry                  | Yes                            | Yes                  | Yes                  |
| year                      | Yes                            | Yes                  | Yes                  |
| Observations              | 402,287                        | 402,287              | 402,287              |
| R <sup>2</sup>            | 0.953                          | 0.953                | 0.953                |

The dependent variable is the Total Factor Productivity (*TFP*) and is estimated using the Olley and Pake algorithm. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *Asset tangibility* denotes tangible assets over total assets; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province-level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

the elasticity with respect to *current ratio* is .002. Therefore, the results align with our expectation that the Chinese firms' availability of cash increases TFP.

Control variables display the expected signs. *Asset tangibility*, which reflects the borrowing capacity of a firm, is positively correlated with TFP. The coefficient on *labor to capital ratio* is positive and significant, meaning that TFP decreases with capital intensity. Firms with a higher ratio of export over sales, display better productivity, which is in line with the trade literature, according to which, more productive firms can pay the fixed cost to enter the export market (Melitz 2003). The last two columns include the variables for external credit availability: *all credit* and *long term credit*. Their inclusion does not alter the sign and significance of the main coefficients of interest. The positive effect of external finance on firms' productivity is consistent with the recent literature on credit constraints (e.g. Li et al. (2018); Chen and Guariglia (2013)).

As argued above, internal finance is expected to be used more efficiently by credit-constrained firms, private firms compared to SOEs, and domestic firms compared to foreign firms. Indeed, foreign firms can use technology, management practices, and operating knowledge from their home country to improve TFP, implying that the effect of internal finance availability on productivity will be more pronounced for domestic firms. We test these assumptions in tables 2.13, 2.14, and 2.15 in the appendix for credit-constrained *versus* non-constrained firms, private *versus* SOE and domestic *versus* foreign firms respectively. As expected, the intensity of the relationships between external financing and firm productivity is weaker for non-constrained, SOEs and foreign firms.

Overall, our results suggest that firms generating enough cash flow manage to improve their productivity through different innovative investments and technology adoption. This results in a TFP-induced decrease in the emissions of  $SO_2$ .

### 2.5.3 Internal finance and $SO_2$ abatement equipment

In this section, we carefully examine if the firm's internal financing is used to purchase pollution abatement equipment. In the same vein, and using the same MEP data, Wang and Chen (1999) reported that the sources of investment in abatement gradually switched from subsidies to the firm's profit, opening up more room for internal finance to acquire pollution abatement equipment.

The MEP data shows how much equipment a firm has accumulated over the year. We use this information to calculate the total number of  $SO_2$  pollution abatement equipment from 2001 to 2007 for each city-industry in our sample. The variable of interest is a count variable which does not follow a normal distribution. In addition, the sample includes a large number of zeros. We rely therefore on the Poisson fixed-effect count model, which belongs to the generalized linear model (GLM) family. It generates unbiased and consistent estimations in the case of a dependent variable containing integers, many zeros, and fixed effects (Santos Silva and Tenreyro 2011). We estimate the following equation:

$$\text{Pollution abatement equipment}_{cit} = \beta_1 \text{cash flow}_{cit} + \beta_2 \text{current ratio}_{cit} + \beta_3 X_{cit} + \gamma_{it} + \gamma_{ct} + \epsilon_{cit} \quad (2.5)$$

where *pollution abatement equipment*<sub>cit</sub> is the number of pollution abatement equipment in a city-industry for each year in our sample. The variables *cash flow*<sub>cit</sub> and *current ratio*<sub>cit</sub> are proxies for internal finance as defined in section 2.3.2.  $X_{cit}$  is a matrix of control variables including *liabilities to asset*<sub>cit</sub>, *sales to asset*<sub>cit</sub>, and *total asset*<sub>cit</sub>. The Poisson Count Model allows us to include several types of fixed effects. We include an industry-year and city-year fixed effect. Our procedure delivers heteroskedastic-robust standard errors clustered at the city level.

**Table 2.8: Internal finance and  $SO_2$  pollution abatement equipment**

|  | Dependent variable: $SO_2$ pollution abatement equipment |                     |                      |                      |                     |                     |                     |
|--|--|---------------------|----------------------|----------------------|---------------------|---------------------|---------------------|
|  | (1)  | (2)                 | (3)                  | (4)                  | (5)                 | (6)                 | (7)                 |
| log(cashflow)                                  | 0.023***<br>(0.006)                                      | 0.095**<br>(0.042)  |                      | 0.074*<br>(0.042)    | 0.0002<br>(0.009)   |                     | 0.001<br>(0.009)    |
| log(current ratio)                             | 0.030***<br>(0.011)                                      |                     | 0.216***<br>(0.065)  | 0.197***<br>(0.066)  |                     | -0.022<br>(0.016)   | -0.022<br>(0.016)   |
| log(liabilities to asset)                      | 0.189***<br>(0.019)                                      | 0.178***<br>(0.019) | 0.181***<br>(0.019)  | 0.187***<br>(0.019)  | 0.179***<br>(0.019) | 0.182***<br>(0.019) | 0.189***<br>(0.019) |
| log(sales to asset)                            | 0.155***<br>(0.011)                                      | 0.157***<br>(0.011) | 0.168***<br>(0.010)  | 0.157***<br>(0.011)  | 0.157***<br>(0.011) | 0.164***<br>(0.010) | 0.154***<br>(0.011) |
| log(total asset)                               | 0.389***<br>(0.004)                                      | 0.376***<br>(0.007) | 0.386***<br>(0.004)  | 0.377***<br>(0.007)  | 0.387***<br>(0.004) | 0.392***<br>(0.004) | 0.391***<br>(0.004) |
| log(cashflow) $\times$ log(total asset)        |  | -0.005*<br>(0.003)  |                      | -0.004<br>(0.003)    |                     |                     |                     |
| log(current ratio) $\times$ log(total asset)   |  |                     | -0.013***<br>(0.005) | -0.012***<br>(0.005) |                     |                     |                     |
| log(cashflow) $\times$ credit constraints      |  |                     |                      |                      | 0.042***<br>(0.011) |                     | 0.034***<br>(0.011) |
| log(current ratio) $\times$ credit constraints |  |                     |                      |                      |                     | 0.094***<br>(0.020) | 0.083***<br>(0.020) |
| industry-year                                  | Yes  | Yes                 | Yes                  | Yes                  | Yes                 | Yes                 | Yes                 |
| city-year                                      | Yes  | Yes                 | Yes                  | Yes Yes              | Yes                 | Yes                 | yes                 |
| Observations                                   | 21,729   | 21,729              | 21,729               | 21,729               | 21,729              | 21,729              | 21,729              |
| R <sup>2</sup>                                 | 0.518  | 0.518               | 0.518                | 0.518                | 0.518               | 0.518               | 0.518               |

This table reports estimates of equation (2.5). *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. The following variables are lagged by one-year: *current ratio*, *cash flow*, *liabilities/assets*, and *sales/assets*. *credit constraints<sub>i</sub>* is a dummy variable taking the value of 1 if the industry is financially dependent. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

Results are displayed in table 2.8. Column 1 includes  $cash\ flow_{cit}$  and  $current\ ratio_{cit}$ . The coefficients on these variables are always positive and significant, meaning that companies better endowed with internal finance are more likely to purchase pollution abatement equipment. Columns 2 to 4 extend the analysis by interacting the industry's size with the internal finance variables. The interaction term allows us to check that small firms have a greater incentive to use their cash flow to invest it in pollution abatement equipment compared to large firms. This is validated as the estimated coefficients on the interaction terms in columns (2) and (3) are negative and significant at the 10% or 1% level. A recent paper (Fan et al. 2021) reports that larger firms complying with environmental policy, enjoy prefer-

ential loan interest rates, and that smaller companies have no option but to reduce the size of the production when they cannot comply with the regulations. Our results suggest that the availability of cash flow may allow the latter to comply with the regulations, thus avoiding the need to reduce production scale. Finally we test in columns 6 and 7 that firms facing credit constraint have a bigger incentive to use their internal finance to acquire pollution equipment abatement. The stronger estimated elasticities validate this for credit-constrained firms, the interaction variables being significant at 1%.

## 2.6 Conclusion

This paper investigates the relationship between credit constraints and pollution emissions in China. Our strategy is built on the model of Andersen (2017), which established that external credit constraints distort the allocation of assets toward tangible assets, which is more conducive to pollution. In contrast, investment in technological improvement (intangible assets) is more likely to decrease the level of emissions. The main intuition behind this result is that banks require collateral to provide a loan, and intangible assets are not valuable for the money-lender. The empirical analysis is rooted in a unique and rich dataset provided by the Ministry of Environmental Protection (MEP) and by the State Environmental Protection Agency (SEPA), the primary source of data on pollutants and waste in China since 1980.

The findings are the following, and in line with Andersen (2017). More external credit constraints biases investment toward tangible assets, as expected, leading to higher emissions of  $SO_2$ . *A contrario*, the availability of internal finance proxied by cash flow and current ratio reduces pollution. Further analysis confirms that three mechanisms are behind this credit constraints-induced emission of  $SO_2$ : the availability of internal credit, which reduces

investment toward tangible assets (1), and facilitates the adoption of green technologies through investment in R&D, improvement of TFP (2), and purchase of pollution abatement equipment (3). In the Chinese context, internal financing is essential, and it is sensitive to the injunctions of the national environmental regulatory policies. Addressing the tendency of bank lending to favour tangible assets, as well as encouraging pollution control investments, particularly within state-owned enterprises, whether through green innovation or emission reduction equipment, would further protect the environment.

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## 2.7 Appendix

**Table 2.9:  $SO_2$  emissions and city ownership, employment measure**

|                          | Dependent variable: $SO_2$ emissions in log |                      |                     |                      |                      |                      |                     |                      |
|--------------------------|---|----------------------|---------------------|----------------------|----------------------|----------------------|---------------------|----------------------|
|                          | (1)   | (2)                  | (3)                 | (4)                  | (5)                  | (6)                  | (7)                 | (8)                  |
|                          | SOE   | Private              | SOE                 | Private              | Foreign              | Domestic             | Foreign             | Domestic             |
| log(asset tangibility)   | 0.100<br>(0.150)                            | 0.246***<br>(0.049)  | 0.095<br>(0.150)    | 0.244***<br>(0.049)  | 0.021<br>(0.207)     | 0.245***<br>(0.045)  | 0.012<br>(0.209)    | 0.241***<br>(0.046)  |
| log(cashflow)            | 0.082<br>(0.054)                            | -0.056***<br>(0.019) | 0.081<br>(0.053)    | -0.055***<br>(0.019) | -0.103*<br>(0.054)   | -0.040**<br>(0.018)  | -0.104*<br>(0.055)  | -0.040**<br>(0.017)  |
| log(current ratio)       | -0.164<br>(0.107)                           | -0.099***<br>(0.031) | -0.169<br>(0.106)   | -0.101***<br>(0.031) | -0.379***<br>(0.145) | -0.095***<br>(0.030) | -0.366**<br>(0.143) | -0.098***<br>(0.030) |
| log(TFP)                 |   |                      | -0.812<br>(1.013)   | -0.539<br>(0.430)    |                      |                      | 1.765<br>(1.533)    | -0.879**<br>(0.383)  |
| $SO_2$ removing capacity | 1.123<br>(1.005)                            | -0.012**<br>(0.005)  | 1.133<br>(1.018)    | -0.012**<br>(0.005)  | 3.990**<br>(1.562)   | -0.011**<br>(0.005)  | 3.998**<br>(1.567)  | -0.011**<br>(0.005)  |
| Observations             | 3,845                                       | 20,538               | 3,845               | 20,538               | 2,341                | 22,042               | 2,341               | 22,042               |
| R <sup>2</sup>           | 0.785                                       | 0.630                | 0.785               | 0.630                | 0.729                | 0.638                | 0.729               | 0.639                |
| log(asset tangibility)   | 0.094<br>(0.110)                            | 0.256***<br>(0.051)  | 0.093<br>(0.110)    | 0.254***<br>(0.051)  | -0.070<br>(0.186)    | 0.265***<br>(0.045)  | -0.071<br>(0.187)   | 0.262***<br>(0.046)  |
| log(cashflow)            | 0.041<br>(0.041)                            | -0.052***<br>(0.020) | 0.040<br>(0.040)    | -0.052***<br>(0.020) | -0.058<br>(0.050)    | -0.038**<br>(0.018)  | -0.058<br>(0.050)   | -0.038**<br>(0.018)  |
| log(current ratio)       | -0.120<br>(0.086)                           | -0.100***<br>(0.032) | -0.121<br>(0.085)   | -0.101***<br>(0.032) | -0.268**<br>(0.104)  | -0.090***<br>(0.031) | -0.266**<br>(0.103) | -0.092***<br>(0.031) |
| log(TFP)                 |   |                      | -0.361<br>(0.811)   | -0.487<br>(0.442)    |                      |                      | 0.267<br>(1.259)    | -0.818**<br>(0.374)  |
| $SO_2$ removing capacity | 1.165<br>(0.850)                            | -0.011**<br>(0.005)  | 1.168<br>(0.851)    | -0.012**<br>(0.005)  | 7.137*<br>(4.137)    | -0.011**<br>(0.005)  | 7.128*<br>(4.133)   | -0.012**<br>(0.005)  |
| Observations             | 5,158                                       | 19,225               | 5,158               | 19,225               | 3,145                | 21,238               | 3,145               | 21,238               |
| R <sup>2</sup>           | 0.761                                       | 0.627                | 0.761               | 0.627                | 0.708                | 0.644                | 0.708               | 0.645                |
| log(asset tangibility)   | 0.270***<br>(0.100)                         | 0.236***<br>(0.052)  | 0.267***<br>(0.100) | 0.234***<br>(0.052)  | 0.053<br>(0.159)     | 0.271***<br>(0.046)  | 0.053<br>(0.159)    | 0.267***<br>(0.046)  |
| log(cashflow)            | 0.012<br>(0.033)                            | -0.050**<br>(0.021)  | 0.011<br>(0.033)    | -0.050**<br>(0.021)  | -0.075*<br>(0.045)   | -0.040**<br>(0.019)  | -0.075*<br>(0.045)  | -0.040**<br>(0.019)  |
| log(current ratio)       | -0.110<br>(0.072)                           | -0.104***<br>(0.034) | -0.112<br>(0.072)   | -0.106***<br>(0.034) | -0.144*<br>(0.080)   | -0.097***<br>(0.032) | -0.144*<br>(0.079)  | -0.099***<br>(0.032) |
| log(TFP)                 |   |                      | -1.020<br>(0.721)   | -0.584<br>(0.460)    |                      |                      | 0.014<br>(1.267)    | -0.775**<br>(0.380)  |
| $SO_2$ removing capacity | 1.035<br>(1.042)                            | -0.011**<br>(0.005)  | 1.044<br>(1.050)    | -0.011**<br>(0.005)  | 8.178***<br>(2.973)  | -0.011**<br>(0.005)  | 8.178***<br>(2.974) | -0.012**<br>(0.005)  |
| Observations             | 6,777                                       | 17,606               | 6,777               | 17,606               | 4,276                | 20,107               | 4,276               | 20,107               |
| R <sup>2</sup>           | 0.738                                       | 0.625                | 0.738               | 0.625                | 0.686                | 0.649                | 0.686               | 0.649                |
| industry-year            | Yes   | Yes                  | Yes                 | Yes                  | Yes                  | Yes                  | Yes                 | Yes                  |
| city-year                | Yes   | Yes                  | Yes                 | Yes                  | Yes                  | Yes                  | Yes                 | Yes                  |

*Asset tangibility* denotes tangible assets over total assets. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *SO<sub>2</sub> removing capacity* is the capacity to remove  $SO_2$  emissions per hour divided by sales. *TFP* stands for Total Factor Productivity and is estimated using the Olley and Pake algorithm. All estimates include control variables. The following variables are lagged by one-year: *current ratio*, *cash flow*, *liabilities/assets*, and *sales/assets*. A city is considered as being dominated by SOEs (foreign firms) if the total industrial output of SOEs (foreign firms) over the total industrial employment exceeds a threshold within a city. All columns control for *total asset*, *liabilities/assets*, and *sales/assets*. The following variables are lagged by one year: current ratio, cash flow, liabilities/assets, and sales/assets. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.10: Credit-constrained versus non-constrained firms (tangible assets versus intangible assets) and internal finance**

|   | Dependent variables: tangible assets and R&D over total assets |                      |                      |                      |                      |                      |
|---|--|----------------------|----------------------|----------------------|----------------------|----------------------|
|   | (1)  | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  |
|   | Tangible to asset  | RD                   | Tangible to asset    | RD                   | Tangible to asset    | RD                   |
| log(cashflow)                           | -0.146***<br>(0.001)   | 0.0003**<br>(0.0001) | -0.147***<br>(0.001) | 0.0003**<br>(0.0001) | -0.146***<br>(0.001) | 0.0003**<br>(0.0001) |
| log(cashflow) × credit constrained      | -0.009***<br>(0.002)   | -0.0001<br>(0.0002)  | -0.009***<br>(0.002) | -0.0001<br>(0.0002)  | -0.009***<br>(0.002) | -0.0001<br>(0.0002)  |
| log(current ratio)                      | -0.021***<br>(0.001)   | 0.0002<br>(0.0001)   | -0.021***<br>(0.001) | 0.0002<br>(0.0001)   | -0.021***<br>(0.001) | 0.0002<br>(0.0001)   |
| log(current ratio) × credit constrained | -0.006***<br>(0.002)   | -0.00004<br>(0.0002) | -0.006***<br>(0.002) | -0.00004<br>(0.0002) | -0.006***<br>(0.002) | -0.00004<br>(0.0002) |
| log(liabilities to asset)               | -0.040***<br>(0.002)   | 0.0004*<br>(0.0002)  | -0.039***<br>(0.002) | 0.0004*<br>(0.0002)  | -0.040***<br>(0.002) | 0.0004*<br>(0.0002)  |
| log(age)                                | 0.019***<br>(0.002)  | 0.00004<br>(0.0003)  | 0.019***<br>(0.002)  | 0.00004<br>(0.0003)  | 0.019***<br>(0.002)  | 0.00004<br>(0.0003)  |
| export to sale                          | -0.001<br>(0.004)  | 0.0002<br>(0.001)    | -0.002<br>(0.004)    | 0.0002<br>(0.001)    | -0.002<br>(0.004)    | 0.0002<br>(0.001)    |
| all credit                              |  |                      | 0.106***<br>(0.008)  | -0.005***<br>(0.002) |                      |                      |
| long term credit                        |  |                      |                      |                      | 0.010***<br>(0.002)  | -0.001**<br>(0.001)  |
| firm                                    | Yes  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| industry                                | Yes  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| year                                    | Yes  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Observations                            | 402,287  | 152,673              | 402,287              | 152,673              | 402,287              | 152,673              |
| R <sup>2</sup>                          | 0.878  | 0.669                | 0.878                | 0.669                | 0.878                | 0.669                |

*Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province level from 2001 to 2007. *credit constraints<sub>i</sub>* is a dummy variable taking the value of 1 if the industry is financially dependent. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.11: Private versus SOE assets structure (tangible assets versus in intangible assets) and internal finance**

|                              | Dependent variables: tangible assets and R&D over total assets |                      |                      |                        |                      |                        |
|------------------------------|--|----------------------|----------------------|------------------------|----------------------|------------------------|
|                              | (1)  | (2)                  | (3)                  | (4)                    | (5)                  | (6)                    |
|                              | Tangible to asset  | RD                   | Tangible to asset    | RD                     | Tangible to asset    | RD                     |
| log(cashflow)                | -0.142***<br>(0.004)   | 0.00004<br>(0.0001)  | -0.142***<br>(0.004) | 0.0001<br>(0.0001)     | -0.142***<br>(0.004) | 0.0001<br>(0.0001)     |
| log(cashflow) × private      | -0.043***<br>(0.004)   | 0.00001<br>(0.0002)  | -0.043***<br>(0.004) | 0.00000<br>(0.0002)    | -0.043***<br>(0.004) | 0.00000<br>(0.0002)    |
| log(current ratio)           | -0.004<br>(0.005)  | 0.0001<br>(0.0001)   | -0.005<br>(0.005)    | 0.00004<br>(0.0001)    | -0.004<br>(0.005)    | 0.00004<br>(0.0001)    |
| log(current ratio) × private | -0.008**<br>(0.004)  | 0.0001<br>(0.0001)   | -0.009**<br>(0.004)  | 0.0001<br>(0.0001)     | -0.008**<br>(0.004)  | 0.0001<br>(0.0001)     |
| log(liabilities to asset)    | -0.036***<br>(0.004)   | 0.0005**<br>(0.0002) | -0.036***<br>(0.004) | 0.0001*<br>(0.0001)    | -0.036***<br>(0.004) | 0.0001**<br>(0.0001)   |
| log(age)                     | 0.019***<br>(0.003)  | 0.00002<br>(0.0005)  | 0.019***<br>(0.003)  | -0.0002***<br>(0.0001) | 0.019***<br>(0.003)  | -0.0002***<br>(0.0001) |
| export to sale               | -0.002<br>(0.006)  | 0.0003<br>(0.0002)   | -0.002<br>(0.006)    | 0.0005***<br>(0.0001)  | -0.002<br>(0.006)    | 0.0005***<br>(0.0001)  |
| all credit                   |  |                      | 0.098***<br>(0.011)  | -0.005**<br>(0.002)    |                      |                        |
| long term credit             |  |                      |                      |                        | 0.009***<br>(0.003)  | -0.001<br>(0.001)      |
| firm                         | Yes  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| industry                     | Yes  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| year                         | Yes  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| Observations                 | 402,287  | 152,673              | 402,287              | 152,673                | 402,287              | 152,673                |
| R <sup>2</sup>               | 0.893  | 0.679                | 0.893                | 0.679                  | 0.893                | 0.679                  |

*Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.



**Table 2.12: Domestic versus Foreign assets structure (tangible assets versus intangible assets) and internal finance**

|                               | Dependent variable   |                      |                      |                        |                      |                        |
|-------------------------------|----------------------|----------------------|----------------------|------------------------|----------------------|------------------------|
|                               | (1)                  | (2)                  | (3)                  | (4)                    | (5)                  | (6)                    |
|                               | Tangible to asset    | RD                   | Tangible to asset    | RD                     | Tangible to asset    | RD                     |
| log(cashflow)                 | -0.142***<br>(0.004) | 0.00004<br>(0.0001)  | -0.142***<br>(0.004) | 0.0001<br>(0.0001)     | -0.142***<br>(0.004) | 0.0001<br>(0.0001)     |
| log(cashflow) × domestic      | -0.005<br>(0.005)    | 0.0003**<br>(0.0001) | -0.005<br>(0.005)    | 0.0003**<br>(0.0001)   | -0.005<br>(0.005)    | 0.0003**<br>(0.0001)   |
| log(current ratio)            | -0.004<br>(0.005)    | 0.0001<br>(0.0001)   | -0.005<br>(0.005)    | 0.00004<br>(0.0001)    | -0.004<br>(0.005)    | 0.00004<br>(0.0001)    |
| log(current ratio) × domestic | -0.022***<br>(0.005) | 0.00002<br>(0.0001)  | -0.022***<br>(0.005) | 0.00001<br>(0.0001)    | -0.022***<br>(0.005) | 0.00002<br>(0.0001)    |
| log(liabilities to asset)     | -0.036***<br>(0.004) | 0.0005**<br>(0.0002) | -0.036***<br>(0.004) | 0.0001*<br>(0.0001)    | -0.036***<br>(0.004) | 0.0001**<br>(0.0001)   |
| log(age)                      | 0.019***<br>(0.003)  | 0.00002<br>(0.0005)  | 0.019***<br>(0.003)  | -0.0002***<br>(0.0001) | 0.019***<br>(0.003)  | -0.0002***<br>(0.0001) |
| export to sale                | -0.002<br>(0.006)    | 0.0003<br>(0.0002)   | -0.002<br>(0.006)    | 0.0005***<br>(0.0001)  | -0.002<br>(0.006)    | 0.0005***<br>(0.0001)  |
| all credit                    |                      |                      | 0.100***<br>(0.011)  | -0.005**<br>(0.002)    |                      |                        |
| long term credit              |                      |                      |                      |                        | 0.010***<br>(0.003)  | -0.001<br>(0.001)      |
| firm                          | Yes                  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| industry                      | Yes                  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| year                          | Yes                  | Yes                  | Yes                  | Yes                    | Yes                  | Yes                    |
| Observations                  | 402,287              | 152,673              | 402,287              | 402,287                | 402,287              | 402,287                |
| R <sup>2</sup>                | 0.893                | 0.679                | 0.893                | 1.000                  | 0.893                | 1.000                  |

*Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.13: Internal/external finance and TFP, credit-constrained versus non-constrained firms**

|   | Dependent variable: TFP in log |                      |                      |
|---|--------------------------------|----------------------|----------------------|
|   | (1)                            | (2)                  | (3)                  |
| log(cashflow)                           | 0.017***<br>(0.0003)           | 0.017***<br>(0.0003) | 0.017***<br>(0.0003) |
| log(cashflow) × credit constrained      | 0.001**<br>(0.0004)            | 0.001**<br>(0.0004)  | 0.001**<br>(0.0004)  |
| log(current ratio)                      | 0.003***<br>(0.0003)           | 0.003***<br>(0.0003) | 0.003***<br>(0.0003) |
| log(current ratio) × credit constrained | 0.001***<br>(0.0003)           | 0.001***<br>(0.0003) | 0.001***<br>(0.0003) |
| log(liabilities to asset)               | 0.009***<br>(0.0004)           | 0.009***<br>(0.0004) | 0.009***<br>(0.0004) |
| log(collateral)                         | 0.042***<br>(0.001)            | 0.042***<br>(0.001)  | 0.042***<br>(0.001)  |
| log(labor to capital)                   | 0.026***<br>(0.0005)           | 0.026***<br>(0.0005) | 0.026***<br>(0.0005) |
| log(total asset)                        | 0.065***<br>(0.001)            | 0.065***<br>(0.001)  | 0.065***<br>(0.001)  |
| log(age)                                | 0.005***<br>(0.0003)           | 0.005***<br>(0.0003) | 0.005***<br>(0.0003) |
| export to sale                          | 0.008***<br>(0.002)            | 0.008***<br>(0.002)  | 0.008***<br>(0.002)  |
| all credit                              |                                | 0.019***<br>(0.001)  |                      |
| long term credit                        |                                |                      | 0.001***<br>(0.0003) |
| firm-ownership                          | Yes                            | Yes                  | Yes                  |
| industry                                | Yes                            | Yes                  | Yes                  |
| year                                    | Yes                            | Yes                  | Yes                  |
| Observations                            | 402,287                        | 402,287              | 402,287              |
| R <sup>2</sup>                          | 0.955                          | 0.955                | 0.955                |

The dependent variable is the Total Factor Productivity (*TFP*) and is estimated using the Olley and Pake algorithm. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *Asset tangibility* denotes tangible assets over total assets; *credit supply* (all and long-term credit) is measured by taking ratio of the bank loan to GDP at the province level from 2001 to 2007. *credit constraints<sub>i</sub>* is a dummy variable taking the value of 1 if the industry is financially dependent. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.14: Internal/external finance and TFP, Private versus SOE**

|                              | Dependent variable: TFP in log |                      |                      |
|------------------------------|--------------------------------|----------------------|----------------------|
|                              | (1)                            | (2)                  | (3)                  |
| log(cashflow)                | 0.013***<br>(0.0003)           | 0.013***<br>(0.0003) | 0.013***<br>(0.0003) |
| log(cashflow) × private      | 0.006***<br>(0.0004)           | 0.006***<br>(0.0004) | 0.006***<br>(0.0004) |
| log(current ratio)           | 0.003***<br>(0.0004)           | 0.003***<br>(0.0004) | 0.003***<br>(0.0004) |
| log(current ratio) × private | -0.0002<br>(0.0005)            | -0.0002<br>(0.0005)  | -0.0002<br>(0.0005)  |
| log(liabilities to asset)    | 0.009***<br>(0.0004)           | 0.009***<br>(0.0004) | 0.009***<br>(0.0004) |
| log(collateral)              | 0.042***<br>(0.001)            | 0.041***<br>(0.001)  | 0.042***<br>(0.001)  |
| log(labor to capital)        | 0.025***<br>(0.0005)           | 0.025***<br>(0.0005) | 0.025***<br>(0.0005) |
| log(total asset)             | 0.065***<br>(0.001)            | 0.065***<br>(0.001)  | 0.065***<br>(0.001)  |
| log(age)                     | 0.006***<br>(0.0003)           | 0.006***<br>(0.0003) | 0.006***<br>(0.0003) |
| export to sale               | 0.007***<br>(0.002)            | 0.007***<br>(0.002)  | 0.007***<br>(0.002)  |
| all credit                   |                                | 0.019***<br>(0.001)  |                      |
| long term credit             |                                |                      | 0.001***<br>(0.0003) |
| firm-ownership               | Yes                            | Yes                  | Yes                  |
| industry                     | Yes                            | Yes                  | Yes                  |
| year                         | Yes                            | Yes                  | Yes                  |
| Observations                 | 402,287                        | 402,287              | 402,287              |
| R <sup>2</sup>               | 0.960                          | 0.960                | 0.960                |

The dependent variable is the Total Factor Productivity (*TFP*) and is estimated using the Olley and Pake algorithm. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *Asset tangibility* denotes tangible assets over total assets; *credit supply* (all and long term credit) is measured by taking ratio of the bank loan to GDP at the province level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.15: Internal/external finance and TFP, Domestic versus Foreign**

|                               | Dependent variable: TFP in log |                      |                      |
|-------------------------------|--------------------------------|----------------------|----------------------|
|                               | (1)                            | (2)                  | (3)                  |
| log(cashflow)                 | 0.017***<br>(0.0004)           | 0.016***<br>(0.0004) | 0.017***<br>(0.0004) |
| log(cashflow) × domestic      | 0.001**<br>(0.0004)            | 0.001**<br>(0.0004)  | 0.001**<br>(0.0004)  |
| log(current ratio)            | 0.003***<br>(0.001)            | 0.003***<br>(0.001)  | 0.003***<br>(0.001)  |
| log(current ratio) × domestic | 0.0003<br>(0.001)              | 0.0003<br>(0.001)    | 0.0003<br>(0.001)    |
| log(liabilities to asset)     | 0.009***<br>(0.0004)           | 0.009***<br>(0.0004) | 0.009***<br>(0.0004) |
| log(collateral)               | 0.042***<br>(0.001)            | 0.041***<br>(0.001)  | 0.041***<br>(0.001)  |
| log(labor to capital)         | 0.025***<br>(0.0005)           | 0.025***<br>(0.0005) | 0.025***<br>(0.0005) |
| log(total asset)              | 0.065***<br>(0.001)            | 0.065***<br>(0.001)  | 0.065***<br>(0.001)  |
| log(age)                      | 0.006***<br>(0.0003)           | 0.006***<br>(0.0003) | 0.006***<br>(0.0003) |
| export to sale                | 0.007***<br>(0.002)            | 0.007***<br>(0.002)  | 0.007***<br>(0.002)  |
| all credit                    |                                | 0.018***<br>(0.001)  |                      |
| long term credit              |                                |                      | 0.001***             |
| firm-ownership                | Yes                            | Yes                  | Yes                  |
| industry                      | Yes                            | Yes                  | Yes                  |
| year                          | Yes                            | Yes                  | Yes                  |
| Observations                  | 402,287                        | 402,287              | 402,287              |
| R <sup>2</sup>                | 0.960                          | 0.960                | 0.960                |

The dependent variable is the Total Factor Productivity (*TFP*) and is estimated using the Olley and Pake algorithm. *Cash flow* is defined as net income + depreciation over assets; *current ratio* is measured as current assets over current liabilities. *Asset tangibility* denotes tangible assets over total assets; *credit supply* (all and long-term credit) is measured by taking the ratio of bank loan to GDP at the province level from 2001 to 2007. Heteroskedasticity-robust standard errors clustered at the firm level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

**Table 2.16: TCZ and SPZ cities in China**

| City        | Code | TCZ | SPZ | City         | Code | TCZ | SPZ |
|-------------|------|-----|-----|--------------|------|-----|-----|
| Linyi       | 3713 | 1   | 0   | Tongling     | 3407 | 0   | 0   |
| Suihua      | 2312 | 1   | 0   | Tianshui     | 6205 | 1   | 0   |
| Wuzhong     | 6403 | 1   | 0   | Lanzhou      | 6201 | 0   | 1   |
| Chuzhou     | 3411 | 1   | 0   | Wuwei        | 6206 | 1   | 0   |
| Fuyang      | 3412 | 1   | 0   | Pingliang    | 6208 | 1   | 0   |
| Suizhou     | 4213 | 1   | 0   | Qingyang     | 6210 | 1   | 0   |
| Huaihua     | 4312 | 1   | 0   | Zhangye      | 6207 | 0   | 0   |
| Zhaotong    | 5306 | 1   | 0   | Jiuquan      | 6209 | 1   | 0   |
| Huaiian     | 3208 | 1   | 0   | Dingxi       | 6211 | 1   | 0   |
| Heze        | 3717 | 1   | 0   | Jinchang     | 6203 | 0   | 0   |
| Hezhou      | 4511 | 1   | 0   | Longnan      | 6212 | 1   | 0   |
| Anshun      | 5204 | 1   | 0   | Jiayuguan    | 6202 | 1   | 0   |
| Tongliao    | 1505 | 1   | 0   | Shijiazhuang | 1301 | 0   | 1   |
| Lu'an       | 3415 | 1   | 0   | Zhangjiakou  | 1307 | 0   | 0   |
| Jinzhong    | 1407 | 1   | 0   | Baoding      | 1306 | 0   | 1   |
| Baoshan     | 5305 | 1   | 0   | Cangzhou     | 1309 | 1   | 0   |
| Ziyang      | 5120 | 1   | 0   | Handan       | 1304 | 0   | 0   |
| Nanchong    | 5113 | 1   | 0   | Qinhuangdao  | 1303 | 1   | 1   |
| Guang'an    | 5116 | 1   | 0   | Langfang     | 1310 | 1   | 0   |
| Yunfu       | 4453 | 1   | 0   | Hengshui     | 1311 | 0   | 0   |
| Chaozhou    | 4451 | 1   | 0   | Xingtai      | 1305 | 0   | 0   |
| Xuancheng   | 3418 | 1   | 0   | Chengde      | 1308 | 0   | 0   |
| Baicheng    | 2208 | 1   | 0   | Tangshan     | 1302 | 0   | 0   |
| Suqian      | 3213 | 1   | 0   | Pingdingshan | 4104 | 1   | 0   |
| Bazhong     | 5119 | 1   | 0   | Xuchang      | 4110 | 1   | 0   |
| Ya'an       | 5118 | 1   | 0   | Nanyang      | 4113 | 1   | 0   |
| Huludao     | 2114 | 1   | 0   | Xinyang      | 4115 | 1   | 0   |
| Baise       | 4510 | 1   | 0   | Anyang       | 4105 | 0   | 0   |
| Matsubara   | 2207 | 1   | 0   | Luoyang      | 4103 | 0   | 1   |
| Bayannaer   | 1508 | 1   | 0   | Zhengzhou    | 4101 | 0   | 1   |
| Wulanchabu  | 1509 | 1   | 0   | Kaifeng      | 4102 | 1   | 0   |
| Zhangjiajie | 4308 | 1   | 0   | Xinxiang     | 4107 | 1   | 0   |
| Chongzuo    | 4514 | 1   | 0   | Luohe        | 4111 | 1   | 0   |
| Zhongwei    | 6405 | 1   | 0   | Zhoukou      | 4116 | 1   | 0   |
| Erdos       | 1506 | 1   | 0   | Hebi         | 4106 | 1   | 0   |
| Jieyang     | 4452 | 1   | 0   | Zhumadian    | 4117 | 1   | 0   |
| Chizhou     | 3417 | 1   | 0   | Shangqiu     | 4114 | 1   | 0   |
| Laiwu       | 3712 | 1   | 0   | Jiaozuo      | 4108 | 0   | 0   |
| Simao       | 5308 | 1   | 0   | Puyang       | 4109 | 1   | 0   |
| Lijiang     | 5307 | 1   | 0   | Sanmenxia    | 4112 | 0   | 0   |
| Sanya       | 4602 | 1   | 0   | Wuhan        | 4201 | 0   | 1   |
| Bozhou      | 3416 | 1   | 0   | Xianning     | 4212 | 0   | 0   |
| Hefei       | 3401 | 1   | 1   | Xiaogan      | 4209 | 1   | 0   |
| Bengbu      | 3403 | 1   | 0   | Yichang      | 4205 | 0   | 0   |
| Wuhu        | 3402 | 0   | 1   | Xiangfan     | 4206 | 1   | 1   |
| Anqing      | 3408 | 1   | 0   | Huanggang    | 4211 | 0   | 0   |
| Huaibei     | 3406 | 1   | 0   | Jingzhou     | 4210 | 1   | 0   |
| Huainan     | 3404 | 1   | 0   | Shiyan       | 4203 | 1   | 0   |
| Ma'anshan   | 3405 | 0   | 0   | Huangyou     | 4202 | 0   | 0   |
| Huangshan   | 3410 | 1   | 0   | Jingmen      | 4208 | 0   | 0   |

**Table 2.17: TCZ and SPZ cities in China (continued)**

| City          | Code | TCZ | SPZ | City        | Code | TCZ | SPZ |
|---------------|------|-----|-----|-------------|------|-----|-----|
| Ezhou         | 4207 | 0   | 0   | Zunyi       | 5203 | 0   | 0   |
| Yongzhou      | 4311 | 0   | 0   | Liupanshui  | 5202 | 1   | 0   |
| Chenzhou      | 4310 | 0   | 0   | Guiyang     | 5201 | 0   | 1   |
| Changsha      | 4301 | 0   | 1   | Nanjing     | 3201 | 0   | 1   |
| Changde       | 4307 | 0   | 0   | Xuzhou      | 3203 | 0   | 0   |
| Xiangtan      | 4303 | 0   | 0   | Yancheng    | 3209 | 1   | 0   |
| Hengyang      | 4304 | 0   | 0   | Lianyungang | 3207 | 1   | 1   |
| Yueyang       | 4306 | 0   | 0   | Nantong     | 3206 | 0   | 1   |
| Zhuzhou       | 4302 | 0   | 0   | Yangzhou    | 3210 | 0   | 0   |
| Yiyang        | 4309 | 0   | 0   | Zhenjiang   | 3211 | 0   | 1   |
| Shaoyang      | 4305 | 1   | 0   | Changzhou   | 3204 | 0   | 1   |
| Loudi         | 4313 | 0   | 0   | Wuxi        | 3202 | 0   | 1   |
| Changchun     | 2201 | 1   | 1   | Shangrao    | 3611 | 0   | 1   |
| Siping        | 2203 | 0   | 0   | Ji'an       | 3608 | 1   | 0   |
| Liaoyuan      | 2204 | 1   | 0   | Nanchang    | 3601 | 0   | 1   |
| Jilin         | 2202 | 0   | 1   | Ganzhou     | 3607 | 0   | 0   |
| Tonghua       | 2205 | 0   | 0   | Xinyu       | 3605 | 1   | 0   |
| Xiamen        | 3502 | 0   | 1   | Jiujiang    | 3604 | 0   | 0   |
| Longyan       | 3508 | 1   | 0   | Pingxiang   | 3603 | 0   | 0   |
| Ningde        | 3509 | 0   | 0   | Jingdezhen  | 3602 | 1   | 0   |
| Putian        | 3503 | 1   | 0   | Yingtian    | 3606 | 0   | 0   |
| Sanming       | 3504 | 0   | 0   | Yinchuan    | 6401 | 0   | 0   |
| Zhangzhou     | 3506 | 0   | 0   | Shizuishan  | 6402 | 0   | 0   |
| Nanping       | 3507 | 1   | 0   | Xining      | 6301 | 1   | 0   |
| Quanzhou      | 3505 | 0   | 0   | Hanzhong    | 6107 | 1   | 0   |
| Linfen        | 1410 | 0   | 0   | Yan'an      | 6106 | 1   | 0   |
| Taiyuan       | 1401 | 0   | 1   | Baoji       | 6103 | 1   | 1   |
| Datong        | 1402 | 0   | 0   | Xianyang    | 6104 | 1   | 1   |
| Yuncheng      | 1408 | 0   | 0   | Weinan      | 6105 | 0   | 0   |
| Changzhi      | 1404 | 1   | 0   | Xi'an       | 6101 | 0   | 1   |
| Xinzhou       | 1409 | 1   | 0   | Shangluo    | 6110 | 1   | 0   |
| Shuozhou      | 1406 | 0   | 0   | Tongchuan   | 6102 | 0   | 0   |
| Jincheng      | 1405 | 1   | 0   | Mianyang    | 5107 | 0   | 1   |
| Luliang       | 1411 | 0   | 0   | Chengdu     | 5101 | 0   | 1   |
| Yangquan      | 1403 | 0   | 0   | Deyang      | 5106 | 0   | 0   |
| Qujing        | 5303 | 0   | 0   | Yibin       | 5115 | 0   | 0   |
| Kunming       | 5301 | 0   | 1   | Meishan     | 5114 | 0   | 0   |
| Yuxi          | 5304 | 0   | 0   | Dazhou      | 5117 | 1   | 0   |
| Lincang       | 5309 | 1   | 0   | Leshan      | 5111 | 0   | 0   |
| Beijing       | 1101 | 0   | 1   | Luzhou      | 5105 | 0   | 0   |
| Nanning       | 4501 | 0   | 1   | Zigong      | 5103 | 0   | 0   |
| Liuzhou       | 4502 | 0   | 0   | Guangyuan   | 5108 | 1   | 0   |
| Guigang       | 4508 | 0   | 0   | Neijiang    | 5110 | 0   | 0   |
| Beihai        | 4505 | 1   | 1   | Suining     | 5109 | 0   | 0   |
| Guilin        | 4503 | 0   | 1   | Panzhuhua   | 5104 | 0   | 0   |
| Qinzhou       | 4507 | 1   | 0   | Tianjin     | 1201 | 0   | 1   |
| Wuzhou        | 4504 | 0   | 0   | Dandong     | 2106 | 1   | 0   |
| Laibin        | 4513 | 0   | 0   | Shenyang    | 2101 | 0   | 1   |
| Hechi         | 4512 | 1   | 0   | Yingkou     | 2108 | 1   | 0   |
| Fangchenggang | 4506 | 0   | 0   | Jinzhou     | 2107 | 0   | 0   |

**Table 2.18: TCZ and SPZ cities in China (continued)**

| City      | Code | TCZ | SPZ | City         | Code | TCZ | SPZ |
|-----------|------|-----|-----|--------------|------|-----|-----|
| Tieling   | 2112 | 1   | 0   | Meizhou      | 4414 | 1   | 0   |
| Fuxin     | 2109 | 0   | 0   | Heyuan       | 4416 | 1   | 0   |
| Chaoyang  | 2113 | 1   | 0   | Shanwei      | 4415 | 0   | 0   |
| Dalian    | 2102 | 0   | 1   | Qingyuan     | 4418 | 0   | 0   |
| Liaoyang  | 2110 | 0   | 0   | Dongguan     | 4419 | 0   | 0   |
| Anshan    | 2103 | 0   | 1   | Harbin       | 2301 | 1   | 1   |
| Panjin    | 2111 | 1   | 0   | Mudanjiang   | 2310 | 1   | 0   |
| Benxi     | 2105 | 0   | 0   | Heihe        | 2311 | 1   | 0   |
| Fushun    | 2104 | 0   | 0   | Qiqihar      | 2302 | 1   | 0   |
| Weifang   | 3707 | 0   | 1   | Jiamusi      | 2308 | 1   | 0   |
| Qingdao   | 3702 | 0   | 1   | Jixi         | 2303 | 1   | 0   |
| Yantai    | 3706 | 0   | 1   | Daqing       | 2306 | 1   | 1   |
| Zaozhuang | 3704 | 0   | 0   | Shuangyashan | 2305 | 1   | 0   |
| Jinan     | 3701 | 0   | 1   | Hegang       | 2304 | 1   | 0   |
| Dezhou    | 3714 | 1   | 0   | Qitaihe      | 2309 | 1   | 0   |
| Liaocheng | 3715 | 1   | 0   | Hohhot       | 1501 | 0   | 0   |
| Binzhou   | 3716 | 1   | 0   | Hulunbeier   | 1507 | 1   | 0   |
| Jining    | 3708 | 0   | 0   | Chifeng      | 1504 | 0   | 0   |
| Tai'an    | 3709 | 0   | 0   | Baotou       | 1502 | 0   | 1   |
| Weihai    | 3710 | 1   | 1   | Wuhai        | 1503 | 0   | 0   |
| Zibo      | 3703 | 0   | 1   |              |      |     |     |
| Dongying  | 3705 | 1   | 0   |              |      |     |     |
| Rizhao    | 3711 | 1   | 0   |              |      |     |     |
| Shanghai  | 3101 | 0   | 1   |              |      |     |     |
| Urumqi    | 6501 | 0   | 1   |              |      |     |     |
| Karamay   | 6502 | 1   | 0   |              |      |     |     |
| Ningbo    | 3302 | 0   | 1   |              |      |     |     |
| Hangzhou  | 3301 | 0   | 1   |              |      |     |     |
| Huzhou    | 3305 | 0   | 0   |              |      |     |     |
| Wenzhou   | 3303 | 0   | 1   |              |      |     |     |
| Quzhou    | 3308 | 0   | 0   |              |      |     |     |
| Shaoxing  | 3306 | 0   | 0   |              |      |     |     |
| Zhoushan  | 3309 | 1   | 0   |              |      |     |     |
| Jinhua    | 3307 | 0   | 0   |              |      |     |     |
| Lishui    | 3311 | 0   | 0   |              |      |     |     |
| Jiaxing   | 3304 | 0   | 0   |              |      |     |     |
| Chongqing | 5001 | 0   | 0   |              |      |     |     |
| Shaoguan  | 4402 | 0   | 0   |              |      |     |     |
| Foshan    | 4406 | 0   | 1   |              |      |     |     |
| Zhanjiang | 4408 | 0   | 1   |              |      |     |     |
| Canton    | 4401 | 0   | 1   |              |      |     |     |
| Shenzhen  | 4403 | 0   | 1   |              |      |     |     |
| Shantou   | 4405 | 0   | 1   |              |      |     |     |
| Maoming   | 4409 | 1   | 0   |              |      |     |     |
| Jiangmen  | 4407 | 0   | 0   |              |      |     |     |
| Zhuhai    | 4404 | 0   | 1   |              |      |     |     |
| Zhongshan | 4420 | 0   | 1   |              |      |     |     |
| Zhaoqing  | 4412 | 0   | 0   |              |      |     |     |
| Huizhou   | 4413 | 0   | 1   |              |      |     |     |
| Yangjiang | 4417 | 1   | 0   |              |      |     |     |

**Table 2.19: Credit constraint from the annual surveys of Chinese manufacturing firms**

|   | CIC | Value |
|---|-----|-------|
| General Purpose Machinery   | 35  | -2.59 |
| Tobacco   | 16  | -1.54 |
| Measuring Instruments and Machinery for Cultural Activity and Office Work           | 41  | -1.34 |
| Textile Wearing Apparel, Footwear, and Caps   | 18  | -1.32 |
| Leather, Fur, Feather and Related Products  | 19  | -1.11 |
| Metal Products  | 34  | -0.93 |
| Printing, Reproduction of Recording Media   | 23  | -0.8  |
| Beverages   | 15  | -0.72 |
| Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products | 20  | -0.72 |
| Transport Equipment   | 37  | -0.72 |
| Furniture   | 21  | -0.65 |
| Artwork and Other Manufacturing   | 42  | -0.62 |
| Textile   | 17  | -0.48 |
| Processing of Food from Agricultural Products                                       | 13  | -0.47 |
| Plastics  | 30  | -0.47 |
| Medicines   | 27  | -0.44 |
| Electrical Machinery and Equipment  | 39  | -0.44 |
| Chemical Fibers   | 28  | -0.41 |
| Articles For Culture, Education and Sport Activity                                  | 24  | -0.4  |
| Foods   | 14  | -0.32 |
| Non-metallic Mineral Products   | 31  | -0.29 |
| Special Purpose Machinery   | 36  | -0.27 |
| Rubber  | 29  | -0.26 |
| Raw Chemical Materials and Chemical Products  | 26  | -0.23 |
| Smelting and Pressing of Non-ferrous Metals   | 33  | -0.1  |
| Communication Equipment, Computers and Other Electronic Equipment                   | 40  | 0.02  |
| Paper and Paper Products  | 22  | 0.07  |
| Smelting and Pressing of Ferrous Metals   | 32  | 0.33  |
| Processing of Petroleum, Coking, Processing of Nuclear Fuel                         | 25  | 0.62  |

Based on Chinese data is calculated at the 2-digit Chinese Industrial Classification (CIC) level. 29 Data available in the years 2004–2006 in the NBC Database. Computation used the aggregate rather than the median external finance dependence at the 2-digit industry level. One reason is the median firm in the annual surveys of Chinese manufacturing firms database often has no capital expenditure.



## Chapter 3

New evidence on the soft budget  
constraint: Chinese environmental  
policy effectiveness in SOE-dominated  
cities

### 3.1 Introduction

China illustrates the dilemma many nations face between the objectives of economic development and poverty reduction, on the one hand, and of reducing pollution, on the other. Environmental protection often is at odds with poverty reduction, as the steps required to reduce poverty may entail costs in terms of pollution to build infrastructure and stimulate growth. That tradeoff holds even more so in the case of China, with provinces at very different stages of economic development, as emphasized in Kahn and Zheng (2016, p.196 and p.198), as follows: “My boss [the provincial governor] . . . knows it is hard to kill two birds [economic growth and a clean environment] with one stone in my city for now”, or provinces adopting the strategy of “ridding the cage of old birds [polluting firms] in favor of new ones [clean and high-skilled firms]”.

Those metaphors evoke the two objectives the central government has pursued since 2000, obeying a model of federalism that is unique, characterized by its dualism (Vahabi 1995), by a specific tradeoff between political cost and economic benefit and, finally, by the still ongoing planning of the economy and concomitant liberalization of market forces (Berglof and Roland 1998; Qian and Roland 1998). As a pure product of those characteristics, the 10th Five Year Plan (FYP), starting in 2001, set environmental objectives at the national level, while the subsequent 11th plan (2006-2010) moved the incentives for protecting the environment to the local level. The emphasis was switched from growth to pollution, implying that in the evaluation of the performances of local officers, the GDP growth rate, fiscal income, industrial value-added, exports and foreign direct investment (FDI), no longer were binding targets carrying veto-power (*yipiao foujue*). Conversely, environmental and energy consumption targets became targets of supreme value, which every mayor had to fulfill; otherwise, the mayor could not pass end-year evaluations successfully.

Has the new model delivered its expected outcomes? The present paper provides an answer to that question. It stresses the efficacy of state regulation by highlighting the strength of Chinese cities’ policy-induced responses. Moreover, it also shows that, while

cities with smaller shares of SOEs have been more sensitive to the new environmental targets and have reduced their emissions of pollutants significantly, cities dominated by state-owned enterprises (SOEs) have not taken similar steps. Their inaction in that regard can be viewed as an effect of the 'soft budget constraint' (SBC) (Kornai et al. 2003). It is a term coined initially by Janos Kornai (1993; 1995; 1998; 2001), who referred to the phenomenon of bailing-out loss-making firms,<sup>1</sup> consequently undermining ex-ante incentives.

The SBC concept sees a straightforward application to the objective of sustainable growth: under rational expectations of being bailed out public (SOE) or private organizations will not be motivated to reach the objective of reducing pollution. What external circumstances, beyond the SBC, mattered for the realization of such environmental objectives in China? Evidence that the cadre rotation system, which transfers officials to new positions every three to four years, may be the reason why short-term gains, including the extraction of rents from local polluting firms, could be prioritized over long-run ones. Studies have shown that cities with more educated mayors reach the environmental Kuznets curve's turning point at lower levels of per capita income (Zheng et al. 2014). Last but not least, holding higher positions than local officials, senior managers of state-owned firms perceived themselves as being above the local law. As a result, some cities are populated by SOEs that violate environmental regulations, while at the same time generating jobs that are essential to evaluations of local mayoral performance.

This paper revisits the issue of the cities' behavior and the ways they react to environmental regulations. We start the analysis by presenting the main characteristics of Chinese environmental policy before 2006 and until 2010, with special emphasis on two key components of that policy. First, we identify the cities targeted by the central government, called "Two Control Zone" (TCZ hereafter), 175 in number with very poor environmental performances. Second, we summarize the SO<sub>2</sub> pollution reduction guidelines provided in the eleventh FYP by the central government, which proposed to align the motivations of govern-

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<sup>1</sup>The role of Chinese banks in rescuing SOEs and dampening the transition towards a green growth pattern has been documented in Maurel et al. (2019)

mental bureaucrats with environmental policy objectives. In sections 3.3 and 3.4, we discuss the empirical specification and the dataset. Section 3.4 summarizes the primary findings. After the policy shock, local leaders were able to lower SO<sub>2</sub> emissions overall. However, in cities with larger shares of SOEs, the same outcome was not reached.

In the following section, thanks to our very rich dataset, we are able to document four different channels, beyond the SBC. SOE-dominated municipalities can behave differently because they predominantly are (or not) non-TCZ cities. They can be (or not) cities where “it is hard to kill two birds ... with one stone” , cities, in other words, may be poorer or wealthier. Cities with large SOE shares potentially can be characterized by elevated industrial concentration, firms investing less in greener projects, or both.

First of all, TCZ cities comprise a special pool of cities that have been selected by the central government for their very poor environmental performances and are subject to particular vigilance. We expect stronger reactions to the SO<sub>2</sub> regulation in those cities. We also pay attention to other policies that can blur the effectiveness of environmental regulation, notably Special Policies Zones (SPZs), and coastal cities. Secondly, wealthier cities are expected to comply at lower cost with the requirement of lesser pollution emissions, as wealth raises the demand for a cleaner environment. The estimation of Kuznets’ curves confirms that wealthier cities undertake SO<sub>2</sub> mitigation faster. Third, large firms are in position to negotiate with local authorities, as they provide work to many employees in the region (Wang et al. 2003). Such bargaining power can translate into weaker compliance with environmental regulations. Fourth, as argued in Huang and Xu (1998), the lack of effective ex-post screening mechanisms in large corporations makes them tend to choose less risky investment projects. In contrast, green projects usually are riskier are more likely to be undertaken by small or private firms.<sup>2</sup> The innovation channel, known also as Porter’s hypothesis (Porter and van der Linde 1995), is investigated by analyzing the impact of environmental policies on Total Factor Productivity (TFP). We distinguish TFP in cities

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<sup>2</sup>SOEs are similar to large corporations because they are usually large as well.

with large SOE presences, large shares of major corporations, and in TCZ *versus* non-TCZ cities. Finally, the main conclusions are drawn in section 3.6.

## 3.2 Environmental policy background

### 3.2.1 TCZ policy under the 10th FYP (2001-2005): a top-down approach

Chinese policymakers decided to take the environmental issue seriously after the sulfur dioxide (SO<sub>2</sub>) peak hurt the country in 1995. In no less than three years, the officials in Beijing proposed and ratified a law regulating SO<sub>2</sub> emissions. In 1998, the '*Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones*' policy, abbreviated as '*Two Control Zone*' (TCZ), was implemented by the central government, to limit the emissions of that pollutant. While the regulation of SO<sub>2</sub> emissions initially was designed to be implemented at the national level, the State Council subsequently chose 175 TCZ cities with very poor environmental records to engage with more effort. Three selection criteria were chosen according to pre-regulation environmental performances. A city was placed under scrutiny if the average annual ambient SO<sub>2</sub> concentration exceeded the national class two standard (0.06 mg/m<sup>3</sup>), if the daily average ambient SO<sub>2</sub> concentration exceeded the national class three standard (0.25 mg/m<sup>3</sup>)<sup>3</sup> or if the city experienced significant SO<sub>2</sub> emissions.<sup>4</sup>

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<sup>3</sup>China has adopted its own air quality standard, which is less stringent than the World Health Organization's standard. China's National Environmental Monitoring Center (CNEMC) collects real-time, hourly air quality data for the country's major cities. The real-time data are available at <http://www.cnemc.cn/>. Major air pollutants, including SO<sub>2</sub>, NO<sub>2</sub>, and PM<sub>10</sub>, are monitored. To evaluate air quality, the Chinese government defines three classes. Class one means that the yearly SO<sub>2</sub> level is less than 0.02 mg/m<sup>3</sup>, or a daily average of less than 0.05mg/m<sup>3</sup>. Class two is less restrictive. The yearly average should not exceed 0.06, with a daily average of about 0.15. Class three corresponds to a bad air quality. The yearly average can exceed 0.10 mg/m<sup>3</sup>; the daily average is 0.25. By contrast, WHO recommends a daily average of less than 0.02 mg/m<sup>3</sup>. For the record, exposure to high SO<sub>2</sub> levels affects health dangerously. According to WHO, "SO<sub>2</sub> can affect the respiratory system and the functions of the lungs and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma, and chronic bronchitis and makes people more prone to infections of the respiratory tract".

<sup>4</sup>A city was designated as an acid rain control zone if:(1) its average PH value of precipitation was equal to or less than 4.5; (2) its sulfate deposition was above the critical load; (3) its SO<sub>2</sub> emissions were large.

The 175 cities are concentrated primarily in two areas: northern China, owing to heavy reliance on coal to power heating systems, and southern China, where the urban-industrial centers emit substantial air pollution and are the sources of severe acid rain. TCZ cities cover 1.09 million square kilometers, in 27 provinces, and they account for 11.4% of the whole of China's territory.

At the national level, the objectives were the following: the emissions of SO<sub>2</sub> were expected to decline successively in 2000 and 2010, and a special role was assigned to TCZ cities, which were responsible for achieving the national class two standard of 0.06 mg/m<sup>3</sup>. The quota of SO<sub>2</sub> emissions set by the central government in 2000 was not to exceed 24.6 million tons – compared with 23.7 million tons in 1997 – and emissions in 2010 were expected to decline even more than in 2000. In 2001, policymakers strengthened the national consistency of the environmental policy, which was called the control policy in the 10th FYP (2001-2005).

TCZ cities were allowed to use four methods to achieve their pollution reduction targets. They could shut down polluting plants, install new equipment, use cleaner-burning coal or adopt stringent monitoring devices. All power stations with less than 50,000 kilowatts of electricity generation capacity fueled by coal with a sulfur content of three percent, had to be shut down.<sup>5</sup> Furthermore, the central government had the power to cancel construction projects that did not meet the objective of lower SO<sub>2</sub> emissions. Industrial plants were forced to satisfy the environmental standards by installing higher-capacity (more expensive) pollution control equipment.<sup>6</sup> Finally, the government carefully monitored the purchases of fuel oil by firms located in TCZ cities. The transportation department was charged with supplying fuel oil with a sulfur concentration of less than two percent or coal with a sulfur concentration of less than one percent.

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<sup>5</sup>Three-hundred and thirty-eight small power units, 784 product lines in small cement and glass plants, 404 lines in iron and steel plants, and 1422 additional pollution sources had closed and, by May 2001, 4492 high-sulfur coal mines had ceased production in the TCZ area (He et al. 2002).

<sup>6</sup>The second policy required the installation of flue gas desulfurization (FGD) equipment on new and existing coal-fired power plants. At the end of 2005, FGD equipment had been installed on 46.2 gigawatts of coal-fired electricity generation capacity—12% of the total; see Cao et al. (2009).

Table 3.1 reports the emissions of SO<sub>2</sub> during three subsequent FYPs, from 1998 to 2010. The emissions of SO<sub>2</sub> rose again after a short drop of two percent in 1998-2001. By the end of 2000, 102 TCZ cities reached the national class two standard.<sup>7</sup> The entry of China into the World Trade Organization in 2001 launched a process of massive industrialization, economic growth and poverty reduction, which was at odds with the achievement of the objective of stricter pollution controls. The consequences of the lack of coordination and the focus on economic growth from local governments led to an historical peak of SO<sub>2</sub> emissions in 2005, which rose by a factor of 45 % over 2002-2005.

The poor results of the environmental policy were attributed to the design of the policy itself. Its main flaw was that the objectives set at the national level were not restrictive enough at the local level. As a result, economic growth was emphasized heavily by the central government, which did not provide local municipalities with incentives to pursue economic growth and pollution control at the same time. Frequently, those objectives turned out to be contradictory and could not be achieved simultaneously (Barbier and Burgess 2019; Brajer et al. 2011; Grossman and Krueger 1995; Lee and Oh 2015).

In 2006, the central government reconsidered its strategy, changing from a top-down to a bottom-up approach. Echoing the academic literature,<sup>8</sup> which has provided extensive research on the motivations of bureaucrats to implement a particular policy, the two main differences introduced in the 11th FYP (2006-2010) from the previous FYP (2001-2005) were the formulation of clear pollution reduction guidelines for the Chinese provinces and the introduction of an environmental target-based evaluation system for the promotion and career advancement of local officials. The target-based evaluation system aimed at promoting efforts toward meeting the objectives considered to be priorities by the central government. It

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<sup>7</sup>Eighty-four-point three percent of the most polluting firms achieved the national target in terms of SO<sub>2</sub> emissions (China Environment Yearbook 2001).

<sup>8</sup>Dewatripont et al. (1999); Alesina and Tabellini (2007) are among the first to argue that the features of mandated tasks largely drive bureaucrats' performances and efforts. The missions must be embedded in a precise interpretation scheme and be linked to explicit performance measures. According to Alesina and Tabellini (2008), bureaucrats choose their effort levels according to two parameters: a concrete objective to reach and the weight of each task in the likelihood of moving up the hierarchical leadership ladder. The performance measures may or may not be correlated with global, organizational objectives.

**Table 3.1: SO<sub>2</sub> reduction (%) during the subsequent FYPs**

| Cities                        | 1998-2001 | 2002-2005 | 2006-2010 | Target  |
|-------------------------------|-----------|-----------|-----------|---------|
| No TCZ                        | 21.00%    | 64.00%    | -11.00%   | -5.00%  |
| TCZ                           | -7.00%    | 38.00%    | -15.00%   | -15.00% |
| No Dominated SOE <sup>a</sup> | -27.00%   | 33.00%    | -15.00%   | -9.00%  |
| Dominated SOE <sup>a</sup>    | 11.00%    | 24.00%    | -15.00%   | -12.00% |
| Full Sample                   | -2.00%    | 45.00%    | -13.00%   | -10.00% |

The list of TCZ is provided by the State Council, 1998. "Official Reply to the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas". The information about the SO<sub>2</sub> level are collected using various editions of the China Environment Statistics Yearbook. We compute the reduction of SO<sub>2</sub> emission using the same methodology as Chen and al.(2018).

*a* (No) dominated SOEs cities refer to cities where the (output, capital, employment) share of SOEs is (below) above a critical threshold, for instance the 60th decile

provided a tool for measuring the success of the local administration, making them accountable. The threat imposed by Beijing forced the mayors and party secretaries to adhere to the national policy. The new incentives are emphasized in Kahn et al. (2015), who consider that they largely are responsible for the success of the new regulation.

The new focus on environmental concerns from both the central and local governments was followed by immediate and measurable consequences: from 2006 to 2010 the average growth rate of SO<sub>2</sub> emissions fell by 13% (full sample), as reported in Table 3.1; most TCZ cities (95 %) were able to reach the national class two standard for SO<sub>2</sub> concentrations, with no cities reporting values exceeding the national class three standard (Ministry of Environmental Protection of the People's Republic of China 2011). Local officials in TCZ cities paid more attention to the environmental downsides of economic growth. They faced a more demanding target: -15% (TCZ cities), compared with minus five percent (non-TCZ cities) and performed better with respect to the objective, achieving a SO<sub>2</sub> reduction of -15%, while non-TCZ cities reached only -11%.



### 3.3 Empirical specification

Our identification strategy is based on the qualitative change in the environmental strategy from a top-down to a bottom-up approach in 2006, which split the time span into two sub periods: 2001-2005, corresponding to the 10th FYP, and 2006-2010, corresponding to the 11th FYP. The variable *Period* measures the effect of the introduction of more stringent and accountable environmental objectives after 2005 and the launching of the 11th FYP.

Our treatment variable  $target_i$  is a measure of policy intensity: the reduction SO2 mandated from 2006 onward, available at the provincial level, which therefore allows for geographical differences in treatment intensity. From the information on the policy available at the province level, we proxy the intensity of the regulation at the city level (see below).

One concern is the influence of the most polluting industries on the probability of a given city to receive a more stringent reduction mandate. If such a relationship holds, an endogeneity bias needs to be addressed: environmental policy influences the pattern of SO2 emissions, while the shares of the most polluting industries determine the other way around the level of pollution and the probability of being required to address that level of pollution in a more stringent way.<sup>9</sup> Polluted sectors  $k$  is a dummy variable taking the value one for heavily polluting industries  $k$ , and zero for less polluting ones. It controls for the double causality running from the  $Target_i$  policy to pollutant emissions and *vice versa*.

We end-up with a difference-in-difference (DD) design, that accounts for the above three levels of variability and allows us to isolate the effects of stricter environmental policies before and after the 11th FYP on the most polluting industries. Our variable of interest is therefore the  $Target_i$  policy times the 11th FYP period times the Polluted sectors  $k$  capturing the most polluting industries in China.

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<sup>9</sup>Another potential bias results from the fact that urban sectors affected more severely by the regulation may exit the market. If so, the regression falsely will impute a reduction in pollution to the regulation. City sector level observations in our dataset allow us to probe that possibility by investigating various samples that operated throughout the entire period (stayers) or not (leavers). Our results are robust and available upon request.

$$\text{Log SO2 emission}_{ikt} = \alpha(\text{Target}_i \times \text{Polluted sectors}_k \times \text{Period}) + \theta X_{ikt} + \nu_{ik} + \lambda_{it} + \phi_{kt} + \epsilon_{ikt} \quad (3.1)$$

Log SO2 emission  $_{ikt}$  is the level of SO2 in city  $i$ , industry  $k$  and at time  $t$ . The equation includes our right-hand-side variable of interest, a set of control variables,  $X_{ikt}$ , and fixed effects. *Period* is a dummy variable, which is set equal to one when  $t$  is later than 2005.

We enter three control variables usually found in the literature (Andersen 2016, 2017), which are which are the total output $_{ikt}$ , total fixed asset $_{ikt}$ , and employment $_{ikt}$  aggregated by the city  $i$ , industry  $k$  and year  $t$ . The specification includes a city-year fixed effect  $\phi_{it}$ , which controls for all city characteristics that differ across them over time, such as productivity, policies and wages;  $\lambda_{kt}$  is an industry-year fixed effect. which captures time-varying industry characteristics, e.g., industry-specific technology and governmental industrial policies. By entering city-industry fixed effects  $\nu_{ik}$ , we address the time invariant differences between the cities' industries, which are key in our approach: while industrial policies are decided at the central level for the whole country, local municipalities orchestrate their implementations differently from one another. In our specification,  $\epsilon_{ikt}$  represents the error term. We expect the estimated coefficient  $\alpha$  to be negative: cities emit less SO2 after 2005 in more polluting industries. For robustness purposes, we also estimate specifications with single fixed effects - city, industry and year, less demanding in terms of degrees of freedom, but commonly found in the literature.

China's political pecking order of firms is reinforced by a systematic misallocation of financial resources (Dollar and Wei 2007) with credit allocations being biased in favor of SOEs (Brandt and Li 2003; Ferri and Liu 2009; Hale and Long 2011; Huang 2003), whatever their compliances with central governmental objectives in the FYP. SOEs in China also benefit from more substantial bargaining power when it comes to negotiating pollution taxes (Wang et al. 2003; Wang and Wheeler 2005). As a result, SOEs are less sensitive to environmental regulatory tightening because of their stronger bargaining powers and easier access to credit.

To assess the lesser sensitivity of SOEs to regulation, besides the spatial, industrial and time dimensions, we split the sample into two subsamples, according to  $\text{Share SOE}_i$ . That variable is a proxy for the presence of SOEs in city  $i$ , above or below a certain threshold.<sup>10</sup> We expect cities with more private firms to react in more vigorous ways because policymakers put more pressure on them, while SOE-dominated cities enjoy softer budget constraints and, hence, cope more easily with regulation. The coefficient  $\alpha$  should therefore be larger (smaller, or insignificant) in absolute value in the subsample in which  $\text{Share SOE}_i$  is smaller (larger). In all regressions, the standard errors are clustered by industry.

## 3.4 Data

Our key interest is in SO<sub>2</sub> emissions, which are available at the city–industry–year level. Using various data sources, we construct a dataset including environmental, industrial and economic information at the city–industry–year level over the 2002-2007 period.

### 3.4.1 SO<sub>2</sub> emissions

The Ministry of Environmental Protection (MEP) has mandated that the State Environmental Protection Agency (SEPA) collect information on the primary sources of pollutants and waste in China since 1980. SEPA has monitored firms in 39 major industrial sectors that are considered to be heavy polluters. Those firms are required to report basic information, such as company name, address, and output. They also answer a very detailed questionnaire about the emissions of major pollutants (e.g., wastewater, CO<sub>2</sub>, SO<sub>2</sub>, industrial smoke and dust). Based on those surveys, the data on pollutants on which we rely are available only at the city level.

As reported by Wu et al. (2017) and by Jiang et al. (2014), the resulting dataset covers 85% of the emissions of major pollutants in China. The MEP has implemented strict proce-

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<sup>10</sup>We check the robustness of the results by resorting at different thresholds: the 60th, 70th and 80th deciles.

dures, such as unexpected site visits by experts, to ensure that firms do not misreport their emissions. Having access to the statistics of SO<sub>2</sub>, a primary air pollutant, our left-hand side variable is Log SO<sub>2</sub> emission  $_{ikt}$ , which is the logarithm of SO<sub>2</sub> emissions in city  $i$ , industry  $k$  and year  $t$ , for 535 four-digit industries, across 270 cities from 2002 to 2007. We set Polluted sectors  $_k$  equal to one when an industry emits more than 68,070 tons of SO<sub>2</sub> (top 25% of the most polluting sectors).

The emissions of SO<sub>2</sub> reached a peak in 2005 at 32.41 million tons (China Statistical Yearbook on Environment 2005). Of the 522 cities monitored by the Chinese Ministry of Environment, about 400 reported annual average levels of SO<sub>2</sub> that met the class two national standard (0.06 mg/m<sup>3</sup>) and 33 cities fell into the worst category (0.10 mg/m<sup>3</sup>). Two years after the 11th FYP was launched, the situation had changed slightly, according to the Ministry of Environment in its annual report on the state of the Chinese environment. Seventy-nine percent of the audited cities met class two requirements, which is two percentage points better than in 2005. Regarding class three criteria, less than 1.2% of the cities exceeded the threshold, which corresponds to an improvement of four percentage points from 2005. The most polluted cities are located in Shanxi, Guizhou, Inner Mongolia, and Yunnan provinces.

### 3.4.2 Ownership

The National Bureau of Statistics of China (NBS) distinguishes manufacturers with sales exceeding RMB 5 million for both non-SOEs and SOEs. The survey contains detailed information on the names, addresses, four-digit Chinese industrial classifications (CIC), ownership, financial variables, output, sales and fixed assets, at the firm level. It is aggregated at the city–industry–year level to be merged with the dataset on SO<sub>2</sub> emissions.

Summary statistics on the economic importances of SOEs are reported in Table 3.2. SOEs represent large shares of Chinese cities' economies, which varies from 24% (output) to 34% (capital). Those shares are significantly smaller in the richest areas, dropping to 11%

**Table 3.2: Economic importance of SOE's (in %)**

| index                | Output share SOE <sub><i>i</i></sub> | Capital share SOE <sub><i>i</i></sub> | Employment share SOE <sub><i>i</i></sub> |
|----------------------|--------------------------------------|---------------------------------------|--|
| Full sample          | 23.9                                 | 34.1                                  | 28.0                                     |
| Central              | 27.3                                 | 40.0                                  | 32.1                                     |
| Coastal              | 11.4                                 | 18.6                                  | 12.4                                     |
| Northeast            | 25.6                                 | 39.0                                  | 34.0                                     |
| Northwest            | 37.5                                 | 43.8                                  | 42.5                                     |
| Southwest            | 28.9                                 | 41.5                                  | 34.0                                     |
| Eastern              | 15.6                                 | 24.3                                  | 18.8                                     |
| Western              | 34.7                                 | 44.9                                  | 39.6                                     |
| No TCZ               | 22.3                                 | 32.4                                  | 27.3                                     |
| TCZ                  | 25.3                                 | 35.7                                  | 28.7                                     |
| Concentrated city    | 32.0                                 | 43.0                                  | 36.0                                     |
| No Concentrated city | 15.0                                 | 24.4                                  | 19.3                                     |

**Source:** Author's own computation

The list of TCZ is provided by the State Council, 1998.

Output Share SOE<sub>*i*</sub> refers to the ratio of output (respectively capital, employment) of SOEs over the total production (capital, employment) in city *i*.

(output) in coastal areas (respectively 19% capital, 12% employment), and 16% in Eastern areas, while they reach 38% in the Northwest and 35% in Western areas, which are poor.

Interestingly, the output (capital and employment) shares of SOEs in cities wherein industrial concentration is high,<sup>11</sup> reaches 32%, as opposed to 15% in the non-concentrated cities, and 24% for the full sample. Also, the SOE shares are similar in TCZ and non-TCZ cities: about 22% -25% for output, 32% -36% for capital, and 27% -29% for employment.

### 3.4.3 Policy variables: TCZ and target

As documented in Section 3.2, in 1998, the State Council launched a wide-reaching policy to curb SO<sub>2</sub> emissions and to reduce acid rain. Nationwide, 175 cities, located in 27 provinces, were designated as TCZs in order to undertake the subsequent effort for controlling SO<sub>2</sub> emissions. Out of the 270 cities in our dataset, 140 qualified as TCZ cities. Table 3.7 in the appendix provides the list of TCZ cities present in our sample.  $TCZ_i$  is a dummy set equal

<sup>11</sup>The methodology for sampling in two sub-samples, concentrated versus non-concentrated cities, is based upon the computation of an Herfindahl index. Details are exposed in subsection 3.5.3

to one if city  $i$  belongs to that list.

**Table 3.3: GDP per capita, population and SO2 emissions**

**Panel A:**

**GDP per capita and population**

|                     | No TCZ           |                  | TCZ              |                  |
|---------------------|------------------|------------------|------------------|------------------|
|                     | (1)<br>2004-2005 | (2)<br>2006-2007 | (3)<br>2004-2005 | (4)<br>2006-2007 |
| gdp per capita $_i$ | 14,218           | 19,901           | 23,958           | 32,861           |
| population $_i$     | 81               | 84               | 155              | 163              |

**Panel B:**

**SO2 emissions (millions of tonnes)**

|             | No TCZ           |                  |           | TCZ              |                  |           |
|-------------|------------------|------------------|-----------|------------------|------------------|-----------|
|             | (1)<br>2004-2005 | (2)<br>2006-2007 | (2) - (1) | (4)<br>2004-2005 | (5)<br>2006-2007 | (5) - (4) |
| Full sample | 2.624            | 2.833            | 0.209     | 9.736            | 10.294           | 0.558     |
| Central     | 0.991            | 1.004            | 0.013     | 2.138            | 2.154            | 0.016     |
| Coastal     | 0.556            | 0.632            | 0.076     | 3.763            | 3.860            | 0.097     |
| Northeast   | 0.354            | 0.389            | 0.035     | 0.537            | 0.736            | 0.199     |
| Northwest   | 0.265            | 0.360            | 0.096     | 1.110            | 1.097            | -0.012    |
| Southwest   | 0.459            | 0.448            | -0.010    | 2.189            | 2.448            | 0.259     |

**Source:** Authors' own computation

Panel A: gdp per capita $_i$  is in RMB and population $_i$  is in million. gdp per capita $_i$  and population $_i$  are averaged over 2004-2005 and 2006-2007. They are borrowed from the China City Statistical Yearbooks 2002–2007.

Panel B: reported numbers are in millions of tonnes.

All variables are summed over the years 2004 and 2005 and over the years 2006 and 2007.

Table 3.3, Panel A, reports GDP per capita and  $population_i$  for TCZ (non-TCZ cities). Panel B shows SO2 emissions. We notice that TCZ cities are richer. They are also, by definition, making more effort to execute stringent environmental regulations. We retrieve therefore the preliminary evidence of a positive relationship between wealth and the demand for cleaner environmental goods, which is documented in Hering and Poncet (2014).<sup>12</sup> This evidence suggests that SOE-dominated cities, which are richer on average, are therefore potentially more likely to address pollution issues than their counterparts. Overall, SO2 emissions averaged over the 2006-2007 period exceeded the level in the period before, which suggests the existence of a secular trend and the need to control for that trend in the empirical analysis.

<sup>12</sup>In section 3.4, we estimate Kuznets curves to verify that the richest cities pollute less.

Table 3.3, Panel B, provides a more in-depth overview of the patterns of SO2 emissions in the major areas of China. Following Wu et al. (2017), we split the cities into coastal, southwest, central, northeast and northwest areas.<sup>13</sup> In our sample, the coastal area of China is composed of ten provinces and is home to a total of 68 TCZ cities. That area is the wealthiest part of China: It represents the lion’s share of national production and attracts the most significant foreign investment inflows. The southwestern area contains five provinces and 24 TCZ cities, while the central area comprises six provinces and 38 TCZ cities. The northern part of China is split into its western area with six provinces and 13 TCZ cities and the eastern area with three provinces and 11 TCZ cities.

### 3.4.4 Target-based evaluation system

In 2006, the central government provided a clear SO2 pollution reduction guideline for Chinese provinces, called the target-based evaluation policy, which the government adopted to deepen its political ties with the local cadres and to guarantee the fulfillment of the pollution reduction targets. The document stipulated that the provincial leaders had a binding contract with the Ministry of Environment and would bear the responsibility for any failure to fulfill it. Considering that the guideline’s reduction mandates and environmental target-based evaluation systems are not available at the city  $i$  level, but at the provincial level, we apply the following formula.<sup>14</sup> For  $t = 2006$  or  $2007$ :

$$target_{it} = target_i = \Delta SO2_{i,05-10} = \Delta SO2_{p,05-10} \times \sum_{k=1}^{29} \mu_k \frac{Y_{ki,2005}}{Y_{kp,2005}} \quad (3.2)$$

where  $i$  stands for the city,  $p$  for province and  $k$  for the two-digit industry ( $k$  varies from 1 to 29). The left-hand side of the formula for  $target_{it}$  evaluates how much a city should

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<sup>13</sup>The breakdown of provinces here, follows that of Wu et al. (2017). The Central provinces are Anhui, Henan, Hubei, Hunan, Jiangxi, and Shanxi. The Coastal provinces are Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang. The Northeastern provinces are Heilongjiang, Jilin, Liaoning. Northwest are Gansu, Inner Mongolia, Ningxia, Qinghai, Shaanxi, and Xinjiang. The southwestern parts are Chongqing, Guangxi, Guizhou, Sichuan, Yunnan, and Xizang.

<sup>14</sup>Which we borrowed from Chen et al. (2018).

have reduced its SO2 emissions between 2005 and 2010, in units of 10,000 tons. Notation  $\Delta SO2_{p,05-10}$  refers to the reduction mandate at the provincial level and is available for the 31 provinces of China over the 2005-2010 period;<sup>15</sup>  $\mu_k \frac{Y_{ki,2005}}{Y_{kp,2005}}$  is the share of industrial production  $k$ , in city  $i$ , over the total output of industry  $k$ , in province  $p$ , multiplied by  $\mu_k$ ;  $\mu_k$  is a weight that reflects each  $k$  industry's contribution to total industrial SO2 emissions and is set equal to the ratio of SO2 emissions in industry  $k$  over total SO2 emissions. Information about pollution emitted at the two-digit level is obtained from the MEP dataset. All values are as of 2005.

Table 3.4 provides an overall picture of the effort required, on average, by Chinese cities. Not only TCZ cities but also cities along the coastal area need to engage in more effort to meet the requirement in terms of SO2 reduction at the end of the 11th FYP. The majority of cities with larger shares of SOEs are obliged to reduce their SO2 emissions more aggressively.

The list of TCZ cities is provided by the State Council (1998).

(Non) SOE-dominated cities refer to cities where the (output, capital, employment) shares of SOEs are (below) above a critical threshold, for instance, the 60th decile. (Non) Concentrated city refers to cities for which the Herfindahl-Hirschman index is (below) above a critical threshold, for instance, the 60th decile.

### 3.4.5 Control variables

The literature has identified the key determinants of environmental degradation at the firm level (Cole and Elliott 2003; Cole et al. 2008). Capital intensity affects both emissions and intensities of pollution (Hering and Poncet 2014; Andersen 2017). Firm size matters: large industries emit more pollutants. In addition, we use NBS industrial classifications to sort firms according to the sector to which they belong. We rely on the 2002 four-digit CIC and compute total employment, total output and total net fixed assets aggregated at the city-industry-year level. The information is generated from the Annual Survey of Industrial

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<sup>15</sup>For instance, Shanghai Province was expected to reduce its SO2 emissions by 13,000 tons over the period 2005-2010.



**Table 3.4: Mean target (millions of tonnes) in SOEs dominated cities versus no SOEs dominated cities**

| index                | All Cities | no SOEs dominated | SOEs dominated |
|----------------------|------------|-------------------|----------------|
| Full sample          | 0.108646   | 0.101678          | 0.123812       |
| Central              | 0.083170   | 0.065356          | 0.116160       |
| Coastal              | 0.166539   | 0.168427          | 0.154353       |
| Northeast            | 0.053427   | 0.045074          | 0.069373       |
| Northwest            | 0.053444   | 0.035052          | 0.072919       |
| Southwest            | 0.129409   | 0.080275          | 0.194058       |
| Central              | 0.083170   | 0.065356          | 0.116160       |
| Eastern              | 0.129370   | 0.132723          | 0.114789       |
| Western              | 0.100256   | 0.064868          | 0.135644       |
| No TCZ               | 0.052559   | 0.043773          | 0.077367       |
| TCZ                  | 0.160727   | 0.164138          | 0.154775       |
| Concentrated city    | 0.083507   | 0.049193          | 0.122500       |
| No Concentrated city | 0.136124   | 0.137464          | 0.128369       |

**Source:** Author's own computation

The list of TCZ is provided by the State Council, 1998.

(No) SOEs dominated cities refers to cities where the (output, capital, employment) share of SOEs is (below) above a critical threshold, for instance the 60th decile. (No) Concentrated city refers to cities where the Herfindahl index is (below) above a critical threshold, for instance the 60th decile.

Firms (ASIF) conducted by China's NBS for the 2002-2007 period.

## 3.5 Empirical analysis

### 3.5.1 Main results

Table 3.5 (columns 1 to 8) reports the results of estimating equation 1 by OLS. The coefficient of interest measures the effect of the environmental target-based policy for SO2 emissions in the polluting sectors, with particular emphasis on cities dominated by SOEs. The estimated coefficient on the triple interaction term ( $target_i \times \text{Polluted sectors}_k \times \text{Period}$ ) is negative and significant at the five percent (column 1) and one percent (column 2) levels, meaning

that SO2 emissions fell significantly after the launching of the 11th FYP and more so in cities with more intense policy treatment, in line with our expectations. The calculation clearly shows that the reduction in SO2 emissions reached approximately five percent of the average emission of polluted sectors after 2006 in cities not dominated by SOEs.<sup>16</sup> Other control variables have the expected signs: economic growth has degraded the environment severely; GDP, employment and fixed assets are correlated with larger SO2 emissions.

Our key assumption is that the effectiveness of the SO2 policy is weaker in cities dominated by SOEs, which face softer budget constraints. We expect, therefore, a smaller coefficient (smaller in absolute value, or non-significant) for those cities. To test that prediction, we compute SOEs' output shares for each city, along with their capital and employment shares. Then, we split the sample in two: the SOE-dominated subsample (Table 3.5, Panel A) consists of cities for which the SOE output share (capital and employment) is above the 60th decile<sup>17</sup> of the total distribution, while the non-SOE subsample (Table 3.5, Panel B) includes the remaining cities (those below the 60th decile).

Columns 3 and 4 report the estimates obtained when the 60th decile is based on SOEs' industrial output shares (resp. SOEs' capital shares in columns 5-6 and SOEs' employment shares in columns 7-8). The coefficient of interest remains negative and significant in the subsample of cities with fewer SOEs below the 60th decile; the same coefficient becomes insignificant in the subsample of cities with stronger SOE presences (above the 60th decile). The findings confirm that the SO2 policy's effect is attenuated in the polluting sectors dominated by SOEs. SOEs can adopt business strategies less constrained by the new regulation than private firms. Because they receive financial and political support from the local government, SOEs do not need to reduce their emissions or relocate production. The SBC helps them circumvent the policy and absorb the costs associated with it.

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<sup>16</sup>4.9% =  $1 - \exp(0.478 * 0.101678)$ , and 0.101678 is the average  $target_i$  value for non-SOE dominated cities, see table 3.4, column 3. Assuming that SOE dominated cities, where  $target_i$  is set equal to 0.12381 million tons, would react the same way to the target policy, SO2 emissions in those cities could also decrease by five percent.

<sup>17</sup>Similar results hold for the 70th and 80th deciles; they are available upon request.

**Table 3.5: Environmental regulation effectiveness in SOEs dominated cities versus no SOEs dominated cities**

| Panel A: SOEs dominated cities             |  |                      |                      |                   |                      |                   |                      |                   |
|--|--|----------------------|----------------------|-------------------|----------------------|-------------------|----------------------|-------------------|
|  | Dependent variable SO2 emission $_{ikt}$ |                      |                      |                   |                      |                   |                      |                   |
|  | Full sample                              |                      | Output               |                   | Capital              |                   | Employment           |                   |
|  | (1)                                      | (2)                  | (3)                  | (4)               | (5)                  | (6)               | (7)                  | (8)               |
| $output_{cit}$                             | 0.018<br>(0.087)                         | 0.040<br>(0.042)     | 0.864***<br>(0.150)  | 0.017<br>(0.090)  | 0.983***<br>(0.284)  | -0.040<br>(0.085) | 0.857***<br>(0.167)  | 0.020<br>(0.091)  |
| $capital_{cit}$                            | 1.576***<br>(0.582)                      | -0.024<br>(0.173)    | -2.643***<br>(0.656) | -0.465<br>(0.416) | -3.386***<br>(0.835) | -0.444<br>(0.443) | -2.958***<br>(0.771) | -0.494<br>(0.421) |
| $labour_{cit}$                             | 2.769***<br>(0.852)                      | 0.246<br>(0.167)     | 11.075***<br>(1.942) | 1.268*<br>(0.732) | 13.226***<br>(2.190) | 1.536*<br>(0.849) | 12.084***<br>(2.184) | 1.378*<br>(0.768) |
| $target_c \times Period$                   | 0.088<br>(0.109)                         |                      | 0.059<br>(0.335)     |                   | -0.128<br>(0.324)    |                   | 0.147<br>(0.324)     |                   |
| $target_c \times Polluted_i$               | 0.650***<br>(0.150)                      |                      | 1.055***<br>(0.340)  |                   | 0.829**<br>(0.350)   |                   | 0.998***<br>(0.330)  |                   |
| $target_c \times Period \times Polluted_i$ | -0.352**<br>(0.156)                      | -0.478***<br>(0.146) | -0.360<br>(0.442)    | 0.110<br>(0.448)  | -0.059<br>(0.409)    | 0.137<br>(0.407)  | -0.334<br>(0.400)    | -0.168<br>(0.418) |
| City fixed effects                         | Yes                                      | No                   | Yes                  | No                | Yes                  | No                | Yes                  | No                |
| Industry fixed effects                     | Yes                                      | No                   | Yes                  | No                | Yes                  | No                | Yes                  | No                |
| Year fixed effects                         | Yes                                      | No                   | Yes                  | No                | Yes                  | No                | Yes                  | No                |
| City-year fixed effects                    | No                                       | Yes                  | No                   | Yes               | No                   | Yes               | No                   | Yes               |
| Industry-year fixed effects                | No                                       | Yes                  | No                   | Yes               | No                   | Yes               | No                   | Yes               |
| City-industry fixed effects                | No                                       | Yes                  | No                   | Yes               | No                   | Yes               | No                   | Yes               |
| Observations                               | 61,297                                   | 61,297               | 18,381               | 18,381            | 18,367               | 18,367            | 18,350               | 18,350            |
| R <sup>2</sup>                             | 0.432                                    | 0.878                | 0.470                | 0.892             | 0.461                | 0.887             | 0.474                | 0.893             |

| Panel B: no SOEs dominated cities          |  |                      |                     |                      |                     |                      |                     |                      |
|--|--|----------------------|---------------------|----------------------|---------------------|----------------------|---------------------|----------------------|
|  | Dependent variable SO2 emission $_{ikt}$ |                      |                     |                      |                     |                      |                     |                      |
|  | Full sample                              |                      | Output              |                      | Capital             |                      | Employment          |                      |
|  | (1)                                      | (2)                  | (3)                 | (4)                  | (5)                 | (6)                  | (7)                 | (8)                  |
| $output_{cit}$                             | 0.018<br>(0.087)                         | 0.040<br>(0.042)     | -0.167*<br>(0.099)  | 0.024<br>(0.043)     | -0.141*<br>(0.080)  | 0.020<br>(0.040)     | -0.153*<br>(0.090)  | 0.024<br>(0.043)     |
| $capital_{cit}$                            | 1.576***<br>(0.582)                      | -0.024<br>(0.173)    | 2.846***<br>(0.457) | 0.292<br>(0.219)     | 2.950***<br>(0.472) | 0.297<br>(0.213)     | 2.729***<br>(0.448) | 0.287<br>(0.216)     |
| $labour_{cit}$                             | 2.769***<br>(0.852)                      | 0.246<br>(0.167)     | 2.319***<br>(0.706) | 0.087<br>(0.141)     | 2.230***<br>(0.672) | 0.094<br>(0.133)     | 2.199***<br>(0.698) | 0.089<br>(0.140)     |
| $target_c \times Period$                   | 0.088<br>(0.109)                         |                      | 0.058<br>(0.112)    |                      | 0.055<br>(0.114)    |                      | 0.036<br>(0.113)    |                      |
| $target_c \times Polluted_i$               | 0.650***<br>(0.150)                      |                      | 0.580***<br>(0.160) |                      | 0.581***<br>(0.159) |                      | 0.573***<br>(0.159) |                      |
| $target_c \times Period \times Polluted_i$ | -0.352**<br>(0.156)                      | -0.478***<br>(0.146) | -0.323**<br>(0.160) | -0.558***<br>(0.154) | -0.354**<br>(0.162) | -0.571***<br>(0.152) | -0.324**<br>(0.162) | -0.567***<br>(0.154) |
| City fixed effects                         | Yes                                      | No                   | Yes                 | No                   | Yes                 | No                   | Yes                 | No                   |
| Industry fixed effects                     | Yes                                      | No                   | Yes                 | No                   | Yes                 | No                   | Yes                 | No                   |
| Year fixed effects                         | Yes                                      | No                   | Yes                 | No                   | Yes                 | No                   | Yes                 | No                   |
| City-year fixed effects                    | No                                       | Yes                  | No                  | Yes                  | No                  | Yes                  | No                  | Yes                  |
| Industry-year fixed effects                | No                                       | Yes                  | No                  | Yes                  | No                  | Yes                  | No                  | Yes                  |
| City-industry fixed effects                | No                                       | Yes                  | No                  | Yes                  | No                  | Yes                  | No                  | Yes                  |
| Observations                               | 61,297                                   | 61,297               | 42,916              | 42,916               | 42,930              | 42,930               | 42,947              | 42,947               |
| R <sup>2</sup>                             | 0.432                                    | 0.878                | 0.440               | 0.879                | 0.443               | 0.882                | 0.439               | 0.879                |

Note: \* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%  
Heteroskedasticity-robust standard errors in parentheses are clustered by industry

### 3.5.2 Testing for parallel trends

We must check that our empirical strategy satisfies the parallel trends assumption by showing that SO2 emissions trajectories do not differ before the treatment (i.e., before the introduc-

tion of local environmental regulations). One might think, for instance, that certain local governments anticipated the implementation of environmental regulations and decided to enforce it before the treatment year. The test for the parallel trend assumption consists of replacing the treatment variable *Period* with yearly dummies. The new specification becomes:

$$\begin{aligned} \text{Log SO2 emission}_{ikt} = & \sum_{t=2002}^{2007} \alpha(\text{Target}_i \times \text{Polluted sectors}_k \times \text{year}_t) + \\ & \theta X_{ikt} + \nu_{ik} + \lambda_{it} + \phi_{kt} + \epsilon_{ikt} \end{aligned} \quad (3.3)$$

In which  $\text{year}_t$  is a dummy set equal to one when  $t$  ranging from years 2003 to 2007.

The estimate of  $\alpha$  captures the effect of the environmental policy as in the whole sample and in the subsamples of SOE and non-SOE cities before the policy was implemented. If the parallel trend assumption holds,  $\alpha$  should not be significant before 2006. Table 3.6 reports the results. The coefficients all are insignificant at the usual levels before the treatment year, validating the parallel trend assumption. In the remaining columns, we split our sample between SOE cities (columns 3, 5 and 7) and non-SOE cities (columns 2, 4, 6). In the evenly numbered columns, the coefficients for the non-SOE cities are negative and significant from 2006 onward, suggesting the effect of the policy immediately after its introduction. By contrast, the policy does not affect SOE-dominated cities (odd-numbered columns). The estimates are obtained from specifications that control for output, fixed assets and employment.

### 3.5.3 Diffusion channels at work under the soft budget constraint

Four diffusion channels are documented in this section. First, we look at TCZ cities, where we expect a stronger reaction to environmental regulation. We pay attention to other policies mandated by the central government, such as Special Policies Zones (SPZ) and Go West policies, which emphasize economic growth objectives. Second, we estimate Kuznets' curves

**Table 3.6: Test of parallel trend assumption**

|                                       | Estimate of $\alpha$ , equation 3.3 on page 194 |                      |                   |                      |                   |                      |                   |
|---------------------------------------|---|----------------------|-------------------|----------------------|-------------------|----------------------|-------------------|
|                                       | Output  |                      |                   | Capital              |                   | employment           |                   |
|                                       | (1)   | (2)                  | (3)               | (4)                  | (5)               | (6)                  | (7)               |
| <i>year<sub>t</sub></i> varying from: | Full sample                                     | No SOE               | SOE               | No SOE               | SOE               | No SOE               | SOE               |
| 2003                                  | -0.110<br>(0.243)                               | -0.202<br>(0.254)    | -0.797<br>(0.687) | -0.171<br>(0.249)    | -0.547<br>(0.686) | -0.187<br>(0.249)    | -0.341<br>(0.616) |
| 2004                                  | -0.037<br>(0.239)                               | -0.229<br>(0.262)    | -0.254<br>(0.682) | -0.199<br>(0.257)    | 0.108<br>(0.669)  | -0.219<br>(0.259)    | 0.149<br>(0.590)  |
| 2005                                  | -0.344<br>(0.268)                               | -0.281<br>(0.288)    | -0.279<br>(0.780) | -0.271<br>(0.284)    | -0.211<br>(0.776) | -0.274<br>(0.287)    | -0.307<br>(0.670) |
| 2006                                  | -0.665**<br>(0.276)                             | -0.908***<br>(0.296) | -0.346<br>(0.805) | -0.875***<br>(0.289) | -0.049<br>(0.801) | -0.880***<br>(0.295) | -0.407<br>(0.718) |
| 2007                                  | -0.578**<br>(0.273)                             | -0.790***<br>(0.285) | -0.352<br>(0.804) | -0.784***<br>(0.279) | -0.020<br>(0.792) | -0.775***<br>(0.284) | -0.414<br>(0.722) |
| Fixed effects:                        | city-year, industry-year, city-industry         |                      |                   |                      |                   |                      |                   |
| Observations                          | 61,297  | 42,916               | 18,381            | 42,930               | 18,367            | 42,947               | 18,350            |
| R <sup>2</sup>                        | 0.878   | 0.879                | 0.892             | 0.882                | 0.887             | 0.879                | 0.893             |

Due to limited space, only the coefficients of interest are presented. \* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%. Heteroscedasticity-robust standard errors in parentheses are clustered by industry

and validate the prediction that wealthier cities enjoy stronger SO<sub>2</sub> mitigation progress. Third, large firms are in a better position to negotiate with local authorities. Following up on that conjecture, we check whether bargaining power translates into weaker compliance with environmental regulation. Fourth, we examine Porter’s theory, according to which environmental regulation can be accommodated by investment in green projects, which enhances productivity.<sup>18</sup> Such green projects are more likely to be undertaken by private firms because large corporations such as SOEs tend to choose safer, more productive investment projects. Beyond the SBC, we investigate to what extent the response of SOEs to environmental regulation is channeled through these four mechanisms. All reported results are obtained with

<sup>18</sup>Porter’s theory has been subject to a vast literature, the controversy being that green projects may well underperform the market because they bypass non-green projects that offer higher returns. In accordance with Porter’s theory, meta-analysis finds that the relationship between firms’ environmental and financial performance is overall positive (Endrikat et al. 2014; Horváthová 2010; Albertini 2013). A recent study (Song et al. (2017)) reports a positive relationship for A-listed listed companies in China. From a more theoretical perspective, Porter and van der Linde (1995) argue that as consumers become more sophisticated and green market segments open up globally, the early mover “clean” companies can gain a lasting competitive edge.

city-year, industry-year, and city-industry fixed effects.<sup>19</sup>

### **First mechanism: policies mandate in cities**

Table 3.7 provides evidence that our results are sensitive to the political incentives that cities are facing. We consider three categories of cities: TCZ cities, Special Policies Zone (SPZ) cities, and finally, cities close to the sea. While pollution reduction clearly is the top political priority for TCZ cities, that goal may differ for SPZ cities and cities far away from the coast with other political aims. The latter include the 'Go West' policy, which refers to a strategy launched in 2000, when the Chinese government decided to boost the economy of the western areas by pouring billions of US dollars into infrastructure, roads, facilities, and improving the skills of the workers (Chen et al. 2018). Implementing the strategy involved offering incentives to firms, especially SOEs, to downsize production in favor of moving their operations to the new cities located in China's Western hinterlands. We enter  $Coastal_i$ , which is set to one if city  $i$  is away from the hinterland and close to the sea, which historically always has been a very attractive area, and it is zero if the city is located in the western areas and affected by the Go West policy.

The other policy is called SPZ. It aims to boost the attractiveness of SPZ cities for foreign firms, exporters, or high-tech firms, which benefit from lower taxes, access to cheaper credit, or subsidies, among other things (Wang and Wei 2008; Hering and Poncet 2014).<sup>20</sup> We set  $SPZ_i$  equal to one if city  $i$  belongs to the SPZ. In our sample, we have 60 SPZ cities and 108 cities adjacent to the sea.

The coefficient of interest is that of  $Target_i \times Polluted\ sectors_k \times Period$ . It remains negative and significant at the one percent level for TCZ cities (column 1) and no longer is significant for non-TCZ cities (column 2). That result is important because it suggests that reduction mandates ( $Target$ ) and TCZ policies (local and central level) are complementary.

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<sup>19</sup>The results with city, industry, and year fixed effects are available upon request.

<sup>20</sup>The SPZ cities include High-technology Industry Development Areas, Economic and Technological Development Areas, and Export Processing Zones.

**Table 3.7: TCZ, Go West, SPZ policies and environmental regulation effectiveness**

|  | Dependent variable SO2 emission $ikt$   |                   |                     |                     |                      |                      |
|--|---|-------------------|---------------------|---------------------|----------------------|----------------------|
|  | TCZ<br>(1)                              | No TCZ<br>(2)     | Coastal<br>(3)      | No Coastal<br>(4)   | SPZ<br>(5)           | No SPZ<br>(6)        |
| $target_c \times \text{Period} \times \text{Polluted}_i$ | -0.528***<br>(0.155)                    | -0.803<br>(0.919) | -0.415**<br>(0.170) | -0.632**<br>(0.267) | -0.494***<br>(0.188) | -1.020***<br>(0.366) |
| Fixed effects:   | city-year, industry-year, city-industry |                   |                     |                     |                      |                      |
| Observations   | 43,684                                  | 17,613            | 33,662              | 27,635              | 28,078               | 28,760               |
| R <sup>2</sup>   | 0.875                                   | 0.901             | 0.880               | 0.888               | 0.868                | 0.893                |

\* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%. Heteroscedasticity-robust standard errors in parentheses are clustered by industry

Interestingly, the responses of cities located in the hinterlands (*Noncoastal*) to the regulation is -0.632, while it is -0.415 for coastal areas. Finally, as expected, the tradeoff between growth and pollution reduction is biased towards growth in SPZ cities, for which the coefficient of interest is smaller, in absolute value, than that of non-SPZ cities (-0.494 for SPZ versus -1.020 for Non-SPZ). The findings suggest the possible influence of politics on the performances of cities dominated by SOEs.<sup>21</sup>

### Second mechanism: level of concentration

We now examine the effects of firm size and industrial concentration on environmental regulation's effectiveness. Large corporations are more likely to select safer investment projects, while green and risky projects are undertaken by small or private firms. In addition, large firms can influence local authorities concerning the effective enforcement of environmental regulations, which is an aspect of the SBC. If that is true, private firms should be more responsive to the SO2 regulation than SOEs.

Our indicator of industrial concentration is based upon the Herfindahl-Hirschman index (HHI), computed as the average of the sum of the squared market shares of industry  $k$  in city  $i$  over the 2002-2005 period. The values of the computed HHIs range from 0.017 to

<sup>21</sup>The output share of SOEs in TCZ is 25.3% , 29% in the hinterlands, 26% in SPZs, whereas the average output share of SOEs in the total sample reaches 24% .

0.82. We define concentrated cities as those above the 60th decile of the HHI. We rerun our baseline regression on the subsamples of concentrated versus non-concentrated cities. The results are reported in Table 3.8.

**Table 3.8: Industrial concentration and environmental regulation effectiveness**

|  | Dependent variable SO2 emission $_{ikt}$ |                      |
|--|--|----------------------|
|  | Concentrated                             | No Concentrated      |
|  | (1)                                      | (2)                  |
| $target_c \times Period \times Polluted_i$ | -0.048<br>(0.341)                        | -0.565***<br>(0.158) |
| Fixed effects:                             | city-year, industry-year, city-industry  |                      |
| Observations                               | 18,303                                   | 42,994               |
| R <sup>2</sup>                             | 0.906                                    | 0.870                |

\* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%. Heteroscedasticity-robust standard errors in parentheses are clustered by industry

The results confirm that firm size and industrial concentration matter. In cities characterized by low industrial concentration, i.e., below the 60th decile of the Herfindahl index,<sup>22</sup> polluted sectors are sensitive to environmental regulation. The coefficient of interest reaches -0.565 (Table 3.8, column 2), and it is significant at the one percent level. In high-concentrated cities, the estimated coefficient declines to -0.048 (column 1), which is not significantly different from zero, suggesting that larger companies are in stronger bargaining positions and can pursue their own objectives. However, SOEs are large companies: their output share in concentrated cities reaches 32% , while it is only 15% in unconcentrated cities. The SBCs that SOEs face therefore can be explained in part by the high industrial concentration that characterizes the cities in which they operate.

<sup>22</sup>Similar results hold for the 70th and 80th deciles' they are available upon request.



### Third mechanism: Kuznets curve

We address the concern that poorer cities could be less sensitive to environmental regulation because of the correlation between the wealth of the inhabitants and their concerns about the environments in which they live. Empirical evidence supporting that correlation is extensive and reported widely in the Kuznets' curve literature: wealthier households enjoy the financial capacity to consume in line with their preferences for goods and services that protect the environment (Berger 2019; Chen et al. 2018), or they can escape more easily from polluted cities (Chen et al. 2017).

We estimate equation 4 below to estimate the relationships between a Chinese city's SO2 emissions and its characteristics, including log per capita income and its square. Following the academic literature on the environmental Kuznets' curve, we test for whether a "turning point" exists such that when a city's per capita income exceeds a certain level, the association between economic growth and pollution becomes negative. As reported in Table 3.9, we find that wealthier cities enjoy SO2 mitigation progress and that the key turning point ranges from USD 2214 to USD 3872.<sup>23</sup>

$$\begin{aligned} \text{Log SO2 emission}_{ikt} = & \alpha(\ln \text{ gdp per cap})_{ct} + \beta(\ln \text{ gdp per cap})_{ct}^2 + \gamma(\ln \text{ population})_{ct} \\ & + \nu_c + \lambda_k + \phi_t + \epsilon_{ikt} \end{aligned} \tag{3.4}$$

Moreover, further analysis of the results reported in Table 3.9 indicates that cities' characteristics – TCZ versus non-TCZ, concentrated versus unconcentrated, and SOE (non-SOE) dominated cities – matter for the existence of the environmental Kuznets' curve. For non-TCZ cities with high industrial concentration and, what is more important, large SOE shares

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<sup>23</sup> These estimates are lower than the \$ 8,000 per capita, corresponding to the average turning point in the world (Grossman and Krueger 1995). The turning point depends indeed on the type of pollutant (COD, SO2, NOX, PM) used in the empirical specification. For what regards SO2, it is close to our estimate: in Grossman and Krueger (1995) it is \$ 4,000, in Panayotou 1993; 1995 it is around \$ 3,000 per capita, and in Shafik et al. (1992) it is \$ 3,670 per capita. Kahn and Zheng (2016) reports a turning point in China set equal to US\$ 10,000; it is computed from data on particulate matter annual mean concentration (PM10).

(be it based on output, capital or employment) , we are not able to detect a turning point, e.g., a level of per capita income, above which the relationship between local economic growth and pollution levels reverses and becomes negative. We also notice that the share of SOE-dominated cities above the turning point is 78% (only 55% for non-SOE-dominated cities) and 22% (45% ) below it (according to Table 3.9, column 1). That result suggests that most SOE-dominated cities should react to the regulation by reducing their SO2 emissions; because they belong to the segment of the Kuznets' curve along which the relationship between pollution and economic growth is negative.<sup>24</sup> The absence of a reaction to regulation is specific to SOE-dominated cities can be interpreted as symptomatic of the SBC.

#### **Fourth mechanism: environmental regulation-induced TFP improvement**

The evidence of the correlation between pollution abatement, on the one hand, and productivity (scale economies and innovation), on the other hand, is considerable, potentially with a positive or negative sign. For a positive association, the rationale is the following: innovation aims at producing at a lower cost, allowing companies to employ fewer inputs and less dirty energy per unit of output. By imposing a strict lower limit on SO2 emissions, the new regulation forces firms to upgrade or leave the market (Andersen 2016, 2017; Cole et al. 2008). That theory also is known as the Porter hypothesis (Porter and van der Linde 1995). However, the correlation also can be negative. According to compliance cost theory, if the cost of environmental regulation impedes an improvement in productivity, then it results in a decline in industrial performance. A recent paper by Yang et al. (2020) shows that the carbon emission trading system launched in 2017 verifies the Porter hypothesis in that environmental regulation leads to an expansion in employment and reduces carbon emissions.

However, such mechanisms may work only for private firms. A large body of literature

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<sup>24</sup>Our data set documents that the median GDP per capita of SOE-dominated cities is higher by RMB 4 000: RMB 24 730 for SOE-dominated cities and RMB 20 175 for non-SOE-dominated cities. The mean GDP per capita of non-SOE-dominated cities and SOE-dominated cities are not significantly different: RMB 28 458 for the former and RMB 28 539 for the latter.

**Table 3.9: Environmental regulation effectiveness along the Kuznets curves**

|  | Dependent variable: SO <sub>2</sub> emission <sub>it</sub> |                    |                    |                      |                   |                      |                   |                      |                   |                      |               |                   |               |                   |
|--|--|--------------------|--------------------|----------------------|-------------------|----------------------|-------------------|----------------------|-------------------|----------------------|---------------|-------------------|---------------|-------------------|
|  | City   |                    |                    | Concentration        |                   |                      | Output            |                      |                   | Capital              |               |                   | Employment    |                   |
|  | (1)  | (2)                | (3)                | (4)                  | (5)               | (6)                  | (7)               | (8)                  | (9)               | (10)                 |               |                   |               |                   |
| (ln gdp per cap) <sub>it</sub>         | TCZ  | No TCZ             | Concentrated       | No Concentrated      | SOE dominated     | No SOEs dominated    | SOE dominated     | No SOEs dominated    | SOE dominated     | No SOEs dominated    | SOE dominated | No SOEs dominated | SOE dominated | No SOEs dominated |
|  | 3.259***<br>(0.913)  | 0.962<br>(0.937)   | 1.291<br>(1.061)   | 3.569***<br>(0.768)  | 1.023<br>(1.797)  | 3.087***<br>(0.676)  | 2.345<br>(1.821)  | 3.210***<br>(0.687)  | 1.623<br>(1.416)  | 3.711***<br>(0.699)  |               |                   |               |                   |
| (ln gdp per cap) squared <sub>it</sub> | -0.166***<br>(0.045)                                       | -0.033<br>(0.048)  | -0.063<br>(0.053)  | -0.172***<br>(0.038) | -0.040<br>(0.090) | -0.158***<br>(0.034) | -0.117<br>(0.092) | -0.163***<br>(0.034) | -0.081<br>(0.072) | -0.185***<br>(0.034) |               |                   |               |                   |
| (ln population) <sub>it</sub>          | 0.266***<br>(0.094)  | 0.300**<br>(0.138) | 0.434**<br>(0.186) | 0.261***<br>(0.087)  | 0.372*<br>(0.194) | 0.215**<br>(0.087)   | 0.286<br>(0.184)  | 0.216**<br>(0.086)   | 0.080<br>(0.191)  | 0.242***<br>(0.086)  |               |                   |               |                   |
| turning point RMB                      | 18661  | -                  | -                  | 31244                | -                 | 17864                | -                 | 18809                | -                 | 22467                |               |                   |               |                   |
| turning point Dollar                   | 2312   | -                  | -                  | 3872                 | -                 | 2214                 | -                 | 2331                 | -                 | 2784                 |               |                   |               |                   |
| SOEs cities above (below)              | (78%, 22%)   | -                  | -                  | (37%, 63%)           | -                 | (78%, 22%)           | -                 | (77%, 23%)           | -                 | (63%, 37%)           |               |                   |               |                   |
| No SOEs cities above (below)           | (55%, 45%)   | -                  | -                  | (28%, 72%)           | -                 | (55%, 45%)           | -                 | (55%, 45%)           | -                 | (42%, 58%)           |               |                   |               |                   |
| City fixed effects                     | Yes  | Yes                | Yes                | Yes                  | Yes               | Yes                  | Yes               | Yes                  | Yes               | Yes                  |               |                   |               |                   |
| Industry fixed effects                 | Yes  | Yes                | Yes                | Yes                  | Yes               | Yes                  | Yes               | Yes                  | Yes               | Yes                  |               |                   |               |                   |
| Year fixed effects                     | Yes  | Yes                | Yes                | Yes                  | Yes               | Yes                  | Yes               | Yes                  | Yes               | Yes                  |               |                   |               |                   |
| Observations                           | 42,570   | 17,520             | 18,175             | 41,915               | 18,336            | 41,754               | 18,300            | 41,790               | 18,271            | 41,819               |               |                   |               |                   |
| R <sup>2</sup>                         | 0.436  | 0.475              | 0.499              | 0.421                | 0.469             | 0.441                | 0.460             | 0.444                | 0.473             | 0.439                |               |                   |               |                   |

SOEs cities above (below) indicates the share of SOEs dominated cities above and below the turning points, based on the GDP per capita of 2007. No SOEs cities above (below) refers to the share of cities above and below the turning points, whatever the ownership status, based on the GDP per capita of 2007. Due to limited space, only the coefficients of interest are presented \* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%. Heteroscedasticity-robust standard errors in parentheses are clustered by industry

shows that Chinese SOEs report weaker economic performances (Zhang 2004; Dougherty et al. 2007; Qian and Roland 1996) and lower total factor productivity (TFP). Indeed, the objective function does not focus on profit maximization and the soft budget constraint implies that emphasis is placed on competing objectives such as employment, social protection and incumbent protection, leaving aside productivity improvement.

To disentangle those different expectations, we estimate the following equation 5:

$$TFP_{fikt} = \alpha (\text{Target}_i \times \text{Polluted sectors}_k \times \text{Period}) + \zeta_f + \nu_{ik} + \lambda_{it} + \phi_{kt} + \epsilon_{ikt} \quad (3.5)$$

where the dependent variable  $TFP_{fikt}$  is the productivity of firm  $f$  computed with the Olley–Pakes algorithm (Olley and Pakes 1996) at the firm-city-industry-time level. The panel structure of our dataset allows us to address endogeneity issues. First, the inclusion of city-time ( $\lambda_{it}$ ) fixed effects is particularly important to control for the fact that cities faced with the stronger regulatory environmental requirements are also exposed to citywide emission trends. Second, the inclusion of industry-time ( $\phi_{kt}$ ) and city-industry ( $\nu_{ik}$ ) fixed effects removes the trends associated with all firms in a particular industry that are unrelated to the environmental policy. Finally, entering firm fixed effects ( $\zeta_f$ ) removes all unobserved factors contributing to a firm’s TFP within a city, and those effects are allowed to vary over time.

Table 3.10 reports the main coefficients of interest in equation 5, using firm-level data over the 2002-2007 period. Positive coefficients imply that the target-based regulation led to an increase in TFP, supporting the Porter hypothesis according to which strict environmental regulation facilitates technological innovation, whereas negative coefficients indicate that the cost of environmental protection faced by enterprises forces them to bypass investments in innovation and productivity improvement.

The previous discussion shows that the effect of the policy on SO2 emissions is not homo-

geneous across cities depending on status (TCZ versus non-TCZ) and level of development (coastal and SPZ cities, cities below and above Kuznets' turning points). Therefore, we control for such heterogeneity by distinguishing different subsamples. In Table 3.10, we compute the effects of the target-based policy on the TFPs of SOEs versus private firms. Panel A shows the results for firms in TCZ cities (versus non-TCZ cities), and Panel B shows the results for firms in coastal (versus noncoastal) areas. Panel C refers to firms in cities where the level of industrial concentration is high as opposed to low. Finally, we run our model using different turning points obtained from Table 3.9; the results are presented in a separate table 3.11.

Estimates are reported in tables 3.10 and 3.11. In the subsamples of SOE firms located in TCZ cities, the coefficient of interest is 0.144, positive and significant at one percent, confirming the Porter hypothesis. For SOEs in non-TCZ cities and private firms in TCZ cities, it is not significant; therefore, the regulation has no effect on technological improvement. Finally, it is negative and significant for private firms in non-TCZ cities, suggesting that for those firms, the cost of the policy impedes the improvement of productivity. Similar findings hold for coastal (noncoastal) areas, with SOEs (private) in coastal (noncoastal) areas being positively (adversely) affected by environmental regulation: the coefficient for SOEs in coastal areas is set at 0.158, while for private firms in noncoastal areas, it is - 0.087. The level of concentration matters as well, as reflected by the coefficient for SOE firms located in cities where we consider a Herfindahl index below the 60th decile: 0.159, which is significant at the one percent level.<sup>25</sup> This result confirms that smaller firms are more likely to invest in greener technologies that are usually riskier. Table 3.11 confirms that for SOEs located in cities where GDP per capita is sufficiently high (above the turning points), the demand for a better environment and for a cleaner model of production translates into a significant and positive reaction to the regulation. In other cities, this result does not hold anymore.

Overall, the results suggest that policy-induced technological improvement holds only

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<sup>25</sup>Similar results hold for the 70th and 80th deciles; they are available upon request.

**Table 3.10: Reduction mandate - induced change in TFP**

| <b>Panel A: TCZ versus non-TCZ</b>         |                                  |                   |                   |                     |
|--|----------------------------------|-------------------|-------------------|---------------------|
|  | Dependent variable TFP $_{fikt}$ |                   |                   |                     |
|  | SOE                              |                   | PRIVATE           |                     |
|  | (1)                              | (2)               | (3)               | (4)                 |
|  | TCZ                              | No TCZ            | TCZ               | No TCZ              |
| $target_c \times Period \times Polluted_i$ | 0.144***<br>(0.050)              | -0.419<br>(0.429) | -0.022<br>(0.021) | -0.421**<br>(0.188) |
| Firm                                       | Yes                              | Yes               | Yes               | Yes                 |
| City-industry                              | Yes                              | Yes               | Yes               | Yes                 |
| City-time                                  | Yes                              | Yes               | Yes               | Yes                 |
| time-industry                              | Yes                              | Yes               | Yes               | Yes                 |
| Observations                               | 32,078                           | 9,410             | 517,652           | 89,657              |
| R <sup>2</sup>                             | 0.953                            | 0.961             | 0.861             | 0.869               |

| <b>Panel B: Coastal versus non - Coastal</b> |                                  |                  |                   |                     |
|--|----------------------------------|------------------|-------------------|---------------------|
|  | Dependent variable TFP $_{fikt}$ |                  |                   |                     |
|  | SOE                              |                  | PRIVATE           |                     |
|  | (1)                              | (2)              | (3)               | (4)                 |
|  | Coastal                          | No Coastal       | Coastal           | No Coastal          |
| $target_c \times Period \times Polluted_i$   | 0.158**<br>(0.063)               | 0.119<br>(0.098) | -0.012<br>(0.023) | -0.087**<br>(0.036) |
| Firm   | Yes                              | Yes              | Yes               | Yes                 |
| City-industry                                | Yes                              | Yes              | Yes               | Yes                 |
| City-time                                    | Yes                              | Yes              | Yes               | Yes                 |
| time-industry                                | Yes                              | Yes              | Yes               | Yes                 |
| Observations                                 | 19,540                           | 21,948           | 477,084           | 130,225             |
| R <sup>2</sup>                               | 0.955                            | 0.956            | 0.857             | 0.878               |

| <b>Panel C: industrial concentration</b>   |                                  |                    |                   |                   |
|--|----------------------------------|--------------------|-------------------|-------------------|
|  | Dependent variable TFP $_{fikt}$ |                    |                   |                   |
|  | SOE                              |                    | PRIVATE           |                   |
|  | (1)                              | (2)                | (3)               | (4)               |
|  | Concentrated                     | No Concentrated    | Concentrated      | No Concentrated   |
| $target_c \times Period \times Polluted_i$ | 0.068<br>(0.084)                 | 0.159**<br>(0.063) | -0.035<br>(0.032) | -0.015<br>(0.024) |
| Firm                                       | Yes                              | Yes                | Yes               | Yes               |
| City-industry                              | Yes                              | Yes                | Yes               | Yes               |
| City-time                                  | Yes                              | Yes                | Yes               | Yes               |
| time-industry                              | Yes                              | Yes                | Yes               | Yes               |
| Observations                               | 23,054                           | 18,434             | 170,305           | 437,004           |
| R <sup>2</sup>                             | 0.957                            | 0.953              | 0.869             | 0.859             |

Note: \*p<0.1 \*\*p<0.05 \*\*\*p<0.01

Heteroskedasticity-robust standard errors in parentheses are clustered by industry

for SOEs located in TCZ cities, in wealthier cities and to a lesser extent in cities where the level of industrial concentration is lower. Therefore, the weaker policy-induced decrease

in pollution that is reported in Section 3.4 for cities where the share of SOEs is higher does not seem to be driven by an intrinsically smaller effort in technological improvement. Finally, if the environmental policy-induced technological improvement and concomitant decrease in SO2 emissions happens in the richest areas of the country, we cannot exclude this improvement to be due to companies adjusting to the regulation not only by improving their technology, as suggested by our calculations, but also by physically (re)locating to provinces with lower environmental targets or weaker enforcement. The evidence on the pollution haven hypothesis in China is mixed: Wang et al. (2019) do not support the pollution haven hypothesis in domestic trade over 2007–2012, while China seems to be a “pollution heaven” for South-South trade according to Lin and Xu (2019) and Sun et al. (2017).

**Table 3.11: Reduction mandate - induced change in TFP: below and above turning points**

|  | Dependent variable TFP <sub><i>fikt</i></sub> |                |                |                  |  |
|--|---|----------------|----------------|------------------|--|
|  | SOE   |                | PRIVATE        |                  |  |
|  | (1)<br>Above                                  | (2)<br>Below   | (3)<br>Above   | (4)<br>Below     |  |
| $target_c \times Period \times Polluted_i$ | 0.164*** (0.059)                              | 0.101 (0.129)  | -0.015 (0.021) | -0.126 (0.077)   |  |
| Observations                               | 12,359  | 28,393         | 337,534        | 263,001          | Column (4): No Concentrated <sup>a</sup>   |
| R <sup>2</sup>                             | 0.965   | 0.963          | 0.882          | 0.889            | RMB 31244                                  |
| $target_c \times Period \times Polluted_i$ | 0.136** (0.053)                               | 0.101 (0.144)  | -0.017 (0.022) | -0.142(0.069)    |  |
| Observations                               | 20,996  | 19,756         | 449,304        | 151,231          | Column (10): SOE No dominated <sup>a</sup> |
| R <sup>2</sup>                             | 0.955   | 0.966          | 0.867          | 0.896            | RMB 22467                                  |
| $target_c \times Period \times Polluted_i$ | 0.133** (0.053)                               | -0.075 (0.339) | -0.018 (0.022) | -0.291* (0.162)  |  |
| Observations                               | 25,668  | 15,084         | 491,600        | 108,935          | Column (8): SOE No dominated <sup>a</sup>  |
| R <sup>2</sup>                             | 0.954   | 0.968          | 0.866          | 0.902            | RMB 18809                                  |
| $target_c \times Period \times Polluted_i$ | 0.131** (0.053)                               | 0.005 (0.355)  | -0.018 (0.022) | -0.342** (0.147) |  |
| Observations                               | 25,845  | 14,907         | 493,866        | 106,669          | Column (1): TCZ <sup>a</sup>               |
| R <sup>2</sup>                             | 0.954   | 0.968          | 0.866          | 0.903            | RMB 18661                                  |
| $target_c \times Period \times Polluted_i$ | 0.131*** (0.050)                              | 0.034 (0.355)  | -0.019 (0.023) | -0.332** (0.153) |  |
| Observations                               | 26,739  | 14,013         | 502,319        | 98,216           | Column (6): SOE No dominated <sup>a</sup>  |
| R <sup>2</sup>                             | 0.954   | 0.969          | 0.865          | 0.904            | RMB 17864                                  |

The columns Above (Below) refer to firms in cities whose gdp per capita are strictly above (below) the Kuznets turning points. References for the latter are provided in the last column. *a* refers to the number of the column in table 3.9, which provides us with the estimated turning point. For instance 31 244 is estimated using the sub-sample of firms in no-concentrated cities, table 3.9, column 4.

Due to limited space, only the coefficients of interest are presented \* Significance at the 10%, \*\* Significance at the 5%, \*\*\* Significance at the 1%. Heteroscedasticity-robust standard errors in parentheses are clustered by industry

## 3.6 Conclusion

The concept of the SBC introduced by Kornai (1993) is a very fruitful concept that can be applied to a wide range of situations beyond simple transition economics and the economics of socialism. Vahabi (2001; 2014) summarizes these situations, which include many cases of soft budget constraints in market economies. This paper investigates one such situation, namely, the case of SOEs, in terms of reaction to a change in the environmental protection regime. This change consists of a switch from a top-down to a bottom-up approach in 2006 and a new emphasis put on local incentives and target-based policy. We compute the policy-induced reduction of SO<sub>2</sub> emissions at the city level and distinguish between TCZ (non-TCZ), rich (poor) areas, cities where the level of industrial concentration is below (above) a given threshold, and SOE (non-SOE)-dominated cities. The findings demonstrate that SOE-dominated cities did not decrease their SO<sub>2</sub> emissions in response to the environmental regulation.

The empirical analysis is rooted in a unique and rich dataset provided by the Ministry of Environmental Protection (MEP) and by the State Environmental Protection Agency (SEPA), which have been the main source of data on pollutants and waste in China since 1980. The double difference in difference identification strategy allows us to quantify the effect of the environmental regulation on firms' pollution emissions.

Several mechanisms are at work to explain the absence of a reaction in SOE-dominated cities: the influence of the TCZ policy, the location along the Kuznets curve, and the degree of industrial concentration. Given that the share of SOE-dominated cities in TCZ cities is close to the sample average and that SOE-dominated cities are richer, the first two mechanisms are not relevant. On the other hand, SOE-dominated cities are characterized by a higher industrial concentration. As a consequence, these cities are in a position not to comply with the environmentally induced budget constraint hardening, which does not constrain them. Last but not least, we scrutinize policy-induced firms' TFP improvement by controlling for the heterogeneity of cities' responses to environmental regulation, and we find that SOEs are



improving their productivity to adjust to environmental targets under certain circumstances, when they are located in the TCZ, in relatively wealthier areas and above the Kuznets turning points. These results are robust to various specifications and the inclusion of city-year, industry-year and city-industry fixed effects. The TFP analysis includes firms' fixed effects. In addition, we document a slightly negative effect of environmental protection for certain private enterprises, an outcome that may be unique to developing countries, as emphasized in the literature (see Jefferson et al. (2013)). Finally, we cannot exclude that companies can adjust to the regulation not only by improving their technology but also by physically (re)locating to provinces with lower environmental targets or weaker enforcement.

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## Chapter 4

Financial development, environmental  
regulation, and pollution emission:  
evidence from china



## 4.1 Introduction

Developing countries, and more particularly China, are becoming increasingly responsible for global warming. As a consequence, there is a growing awareness that a few prominent emerging countries, such as China and India, need to make a swift transition toward a cleaner economic growth model, which is particularly challenging given the rapid increase in the consumption-oriented middle class.<sup>1</sup> However, this challenge can also open up myriad opportunities. According to the International Energy Agency's World Energy Investment 2019 report, "global power investment is shifting towards emerging and developing countries [with] remarkable investment in renewable. In most regions, low-carbon sources were the largest part of generation spending ... [and] in India, total renewable power investment topped fossil fuel-based power for the third year in a row".<sup>2</sup>

Concerns about environmental issues are also increasing drastically in China, which stands out owing to its environmental disasters and poor air quality.<sup>3</sup> China has experienced numerous disasters, thereby impacting the population's health and aggravating the pre-existing political discontent. In addition, China is known to be a major global air polluter and has witnessed a significant increase in the emission of sulfur dioxide ( $SO_2$ ), or chemical oxygen demand (COD) since its entry into the WTO in 2001 (see figure 4.1).

Environmental damages caused by mass and rapid industrialization was attributable to an excessive need for energy resources and a lack of superior technology (Cole et al. 2008; Kahn and Zheng 2016). Industrial enterprises are responsible for as much as 90%

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<sup>1</sup>OECD report, Development Matters 2019.

<sup>2</sup>IEA. World Energy Investment 2019. Paris: IEA, 2019.

<sup>3</sup>China became the largest COD emitter in the world in 2006, surpassing the United States. In 2018, China still held first place. Moreover, according to the WHO, China hosts over half of the most polluted cities worldwide. To illustrate, Shijiazhuang had only 47 days of good air quality in 2013. In 2017, China had the maximum number of natural disasters worldwide, surpassing the United States and India. In the same year, the province of Hunan suffered a natural disaster-induced direct economic loss of about 59 billion RMB (National Bureau of Statistics of China; Ministry of Ecology and Environment (China)). More statistics can be found here.

of air pollution and 50% of the river pollution in China.<sup>4</sup> In the absence of a well-defined environmental regulation framework, the market forces alone cannot address environmental problems. The agents responsible for the damage, i.e., the firms, lack the incentive to change their environmental behavior without green corporate governance, pressure from the stakeholders, regulation, or, more generally, the contribution of citizens. In such situations, the market can leverage the development of the financial system promoted by the government to indirectly ameliorate the environmental damage by financing environmentally superior technologies or reducing its reliance on polluting assets. Better technology means less energy consumption, better productivity, and as a side result, a decrease in pollution emissions. The role of financial development and environmental situation is relatively new in the literature, with some exceptions for country analysis (De Haas and Popov 2018; Hasan et al. 2009), and in the context of China (Fan et al. 2021; He et al. 2020; Wu et al. 2017; Zhang and Zheng 2019). However, no studies have analyzed the manner in which the transformation of the Chinese banking landscape occurring in the mid-1990 has affected most cities in order to understand the linkage with the environment.

This paper uses the most extensive environmental statistics available in China. This dataset is collected and maintained by the Ministry of Environmental Protection (MEP), which gathers information about the emission of major pollutants such as sulfur dioxide ( $SO_2$ ), wastewater, chemical oxygen demand (COD), and industrial dust. In addition, it encompasses all industrial sectors. To the best of our knowledge, only a few studies (Fan et al. 2021; He et al. 2020; Wu et al. 2017; Zhang and Zheng 2019, among others) have considered such a thin level of pollution emissions in China. We can track the majority of industrial emission of pollutants ( $SO_2$ , COD, and wastewater) for eleven consecutive years (1998–2007) at the level of industries as well as cities. The period covered is also pertinent because China witnessed profound reforms in the banking sector. Moreover, the influence of the State with regard to the allocation of credit diminished over time (see figure 4.2).

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<sup>4</sup>source: <https://m.douban.com/note/144679418/>

Our empirical strategy considers different levels of pollution emissions across city-sector in order to investigate how financial development mitigates credit constraints. We assume that the lack of external funding is detrimental to innovation, technology adoption, and the purchase of pollution abatement equipment (Andersen 2016, 2017; Xu and Kim 2021; Gutiérrez and Teshima 2018), while the banking deregulation, through the easing of the credit constraint, encourages firms to take a step forward in terms of innovation and asset-type re-balancing. As shown in Maurel and Pernet (2020), this productivity improvement brings down  $SO_2$  emissions. The inefficiency of the Chinese financial market is exacerbated by instances of discordance between and within provinces. To capture the financial development and the spatial variability of the credit access, we gather the long-term bank loans by province (normalized by province GDP) in China from the Almanac of China's Finance and Banking. We use two proxies to tackle the malfunctioning of the financial market at the city level. We use the public data available on the website from the China Banking and Insurance Regulatory Commission not only to extract the number of city commercial branches (CCBs) but also to calculate the bank competition index by taking the inverse of the Herfindahl-Hirschman index. To overcome any endogeneity issue caused by financial development, we get each of the three indexes to interact with the sectorial financial dependency (Fan et al. 2015; Rajan and Zingales 1998; Manova et al. 2015). Our salient contribution is the implications of banking restructuring in China to alleviate the prevalent financial constraints on pollution emissions. According to our findings, firms in financially-vulnerable sectors operating in cities with a larger presence of city commercial banks or fiercer competition lower pollution emissions significantly for COD and wastewater, but the statistical linkage with  $SO_2$  is missing.

Our analysis of the repercussions of the local financial development in China further exploits the MEP dataset to gauge two mechanisms. Easier and cheaper access to credit can lead firms to make heavy investments in capital-intensive pollution control activities or foster investment in technology adoption. To begin with, our results are congruent with

recent findings against the backdrop of developing economies. Financial development does not have any impact on the purchase of pollution abatement equipment, whereas pollution reduction primarily comes from investment in technology adoption. The purchase of pollution abatement, however, comes with a heavy price, without productivity gains. Therefore, from the firm's standpoint, it imposes an incremental cost of production (i.e., increases the fixed costs). It is also notable that environmental law enforcement was not rigorous in China during most of our study period. Research has demonstrated that firms do not change their behavior if they expect the detection from the government to be low (Shapira and Zingales 2017; Evans and Stafford 2019) or if the fine remains negligible. We use one of China's most stringent environmental policies to evaluate whether firms are more incentivized to invest in pollution abatement equipment. In 1998, the central government implemented the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone policy, abbreviated as the Two Control Zone (TCZ) policy, in order to curtail pollutant emissions. While the regulation of  $SO_2$  emissions was initially designed to be implemented across the country, the State Council subsequently chose 175 TCZ cities with very poor environmental records to engage with more efforts. The results show that the purchase of pollution abatement equipment firms in TCZ cities rose faster in sectors with greater financial vulnerability when there were more CCBs. Secondly, new technology is capable of altering the practice of cost-cutting and enhancing technical efficiency through a lower need for input and higher productivity, thus reducing pollution emissions. Specifically, investing in technology has two positive ramifications on the plant: a gain in productivity (more sales) and a reduction in input (cost saving). From the firms' perspective, it is seemingly a better solution because it helps adjust the variable cost compared with the pollution abatement equipment, which then raises the fixed costs without requiring an adjustment in productivity. According to our observations, both easier access to credit and stronger competition encourage firms to invest in technology, leading to a reduction in the consumption of energy in the production process.

Then, we document the asset mix mechanism following Andersen (2017) model, where

constrained firms make a relatively higher investment in tangible assets because the bank requires collateral. This over-investment in asset tangibility has a positive correlation with pollution emissions. We depend upon the ASIF dataset to determine whether firms have re-balanced their asset allocation when they have easier access to finance. Finally, we rule out the scale effect hypothesis, which stipulates financial development spurs investment and production without entailing a change in the process. This result confirms that technology adoption has one of the main drivers of pollution reduction financed by better access to finance.

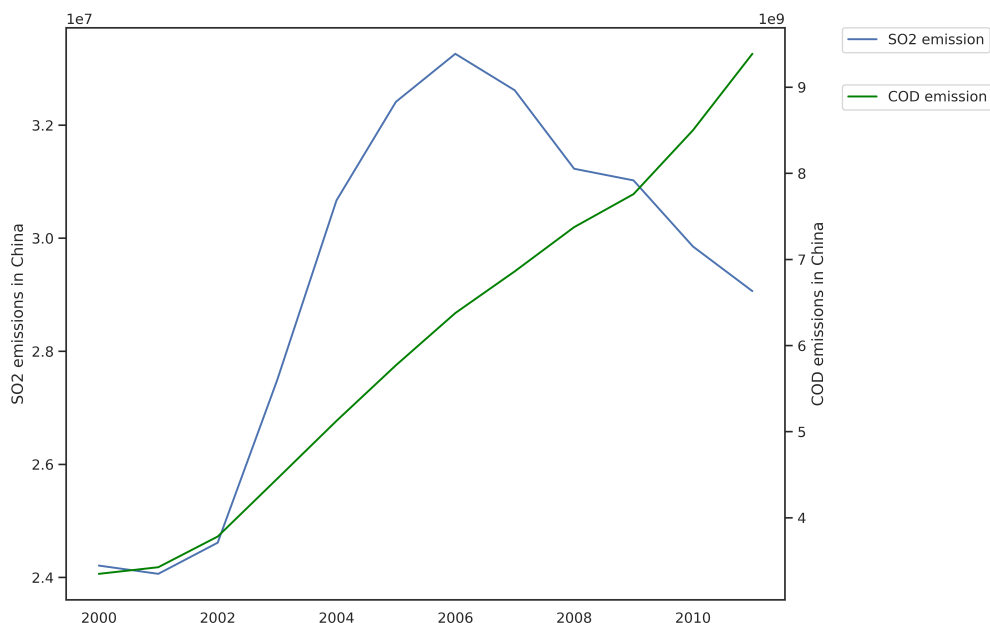
The main contribution of this study to the literature is twofold. First of all, this study is related to the implications of financial development on environmental performance. Recent studies have shown the impact of a financial shock on the environment, including unconventional monetary policy (Goetz 2019), credit supply shock (Levine et al. 2018; Gilje et al. 2016), green finance regulation (Fan et al. 2021), banking deregulation (Andersen 2016; Tamazian et al. 2009). Other studies, meanwhile, have demonstrated the role of the equity market as a driver for lower COD emissions (De Haas and Popov 2018) or environmental risk management (Delis et al. 2018; Sharfman and Fernando 2008; Bauer and Hann 2010). The present paper aims to contribute to this research area by investigating whether the improved efficiency of the banking sector (through financial development) contributes to the sectorial change in pollution emissions across cities between 1998 and 2007. This paper places the emphasis on China because it is an ideal candidate to study the link between financial development and environmental performance. Although it is relatively inefficient (Boyreau-Debray 2003; Dollar and Wei 2007), the Chinese financial market went through fast-paced reforms over a short span of time to cope with the transition to a market-driven economy (Jarreau and Poncet 2014). Banking assets form the majority of loans (i.e., about 85%), and are dominated by the four state-owned commercial banks (Allen et al. 2009). The entry of China to the WTO in 2001 triggered rapid economic growth and environmental

degradation caused by the mismanagement of resources as well as mass industrialization. However, China was not impacted equally, providing considerable spatial variations across coastal and inner-land provinces and giving our estimation strategy sufficient variability to identify the relationship between financial development and environmental performances.

Secondly, our paper is related to the determinant of pollution emissions. There is a large body of research on the economic determinants of pollution, in both developed (e.g. Gray and Deily 1996; Cole et al. 2005; Shadbegian and Gray 2005; Earnhart and Segerson 2012) and developing countries (e.g. Earnhart and Lizal 2006; Cole et al. 2008). Previous studies point to the fact that environmental situations have been affected by environmental regulation (Chay and Greenstone 2005; Greenstone et al. 2012; Greenstone and Hanna 2014). Shapira and Zingales 2017 underscored that the change in pollution emissions in the US was mainly ascribed to environmental regulation. In China, regulation reduces export or production in pollution-intensive activities in highly regulated areas (He et al. 2020; Wu et al. 2017; Wang et al. 2018; Shi and Xu 2018; Zhang et al. 2020), reallocating production away from polluting sectors (Chen et al. 2018; Hering and Poncet 2014), or affects inbound foreign direct investment (Cai et al. 2016). Our contribution to this literature sheds light on the role of easier access to finance and banking deregulation in the reduction of pollution. The utilization of city-level data and an exogenous variable of sectorial financial vulnerability allows us to illuminate evidence of the mechanism between financial development and reduction in pollution emissions.

The remainder of this paper is organized as follows. The role of China's banking system and the development of capital allocation is elucidated in Section 4.2, coupled with the role of financial development and the importance of environmental resolution in 4.3. Our empirical strategy, data, and preliminary evidence are presented in Sections 4.4 and 4.5. Next, Section 4.6 explicates the baseline findings and sources of heterogeneity. Section 4.7 presents the mechanisms. Finally, the paper concludes in Section 4.8.

**Figure 4.1:**  $SO_2$  and COD emissions in China from 2000 to 2011



**Note: Source:** The  $SO_2$  emissions data comes from the Ministry of Environmental Protection and COD comes from <https://ourworldindata.org/>

## 4.2 China's banking system and the development of capital allocation system

China has the world's largest bank loan market (Gao et al. 2019); however, it is relatively inefficient and fragmented. The literature studying the Chinese banking sector is abundant and well-documented. There is no ambiguity on the credit allocation inefficiency caused by the market's regional segmentation (i.e., resources are not mobile across provinces) and mostly favored state-owned enterprises (Boyreau-Debray and Wei 2005; Jarreau and Poncet 2014). Shreds of evidence exist in favor of the notion that private firms are discriminated against in the credit market, especially by state-owned banks. The soft budget constraint is ubiquitous in China, where state-owned firms can easily raise large sums of money, regardless of the profitability or the risk of default.

In China, the People's Bank of China (PBOC) was the only bank before the commencement of the 1978 economic reforms. The particularity of this bank is that it functions both as a central bank and a city bank. The reform restructured the role of the PBOC as a central bank and gave birth to four State-owned Commercial Banks (SBOC), namely the Agriculture Bank of China (ABC), People Construction Bank of China (PCBC), Bank of China (BoC), and Industrial and Commercial Bank of China (ICBC). Each of them was assigned a specific role in the economy. For instance, ABC specialized in supporting economic development in rural areas while the specialization of BoC was in the foreign exchange business. Those four banks have two major shareholders, namely the Ministry of Finance and the China Investment Corporation. The latter is China's sovereign wealth fund, which manages the foreign exchange reserve.

Bank loans are the most common financing source in China, accounting for 75% of the total credit supply (Li et al. 2018). Among that, three quarters were issued by the "Big Four" (Industrial and Commercial Bank of China, China Construction Bank Corporation, Agricultural Bank of China, and Bank of China) under the direct control of the government until 2006. Joint-venture equity banks and city banks account for the remaining quarter. Ferri and Liu (2009) postulate that non-state-owned banks perform better and hold far fewer non-profitable loans (NPL) in their book.

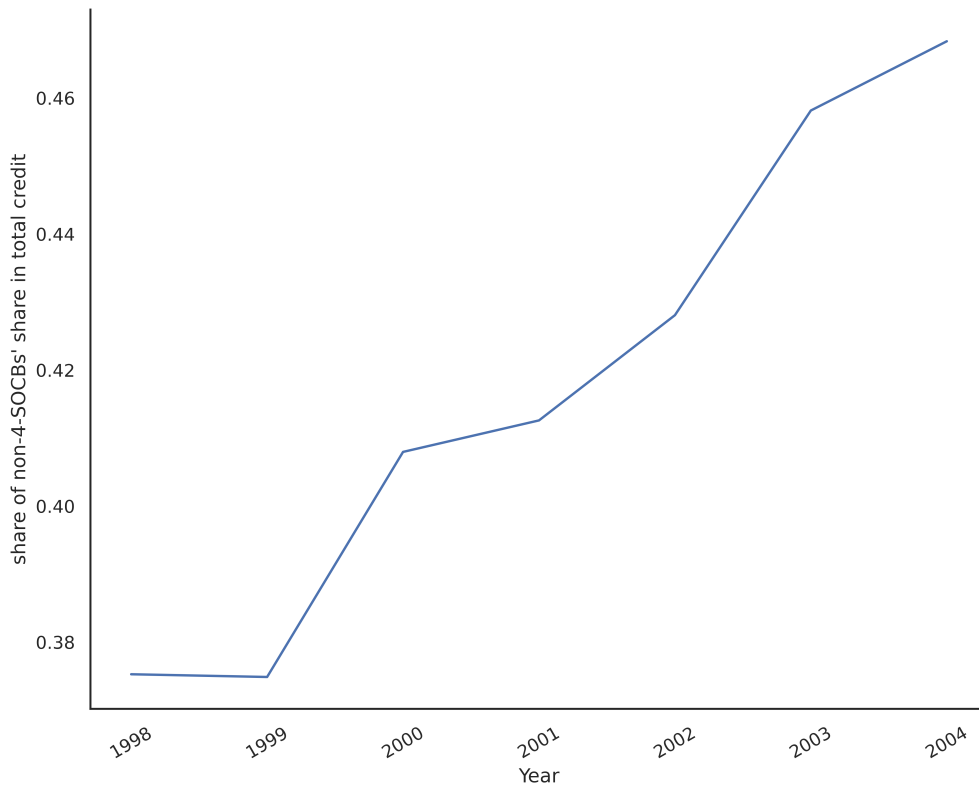
The challenge of banking deregulation in China is accompanied by the large footprint of the "Big Four" (ABC, BOC, ICBC, and CCB) in the country's economic landscape. In 1998, about 60% of the total credit came from the "Big Four" (Almanac of China's Finance and Banking). Following the banking industry's deregulation, the credit share of SOBC was reduced by 14.84% between 1998 and 2004. Some wealthy eastern locations, such as Shanghai, Beijing, and Tianjin, reduced the State footprint by 29.55%, 43.48%, and 37.15%, respectively. On the contrary, less-affluent provinces, mainly located in the western area, rely on loans supplied by the State. The province of Ningxia holds about 77% of loans from the four State-owned Commercial Banks, and in Guizhou, another poor rural province, the



State accounted for 71% of loans in 2004.<sup>5</sup>

Recognizing the four State-owned Commercial Banks' apparent failure to allocate capital efficiently, the Chinese government implemented substantial banking sector restructuring. This process commenced in 1994, when the government allowed more players, primarily with city commercial banks owned by local governments, firms, and private shareholders, as well as in 1996, with the apparition of foreign banks. The market penetration of those banks was gradual, as illustrated in figure 4.2. The market share of non-SOBC was at its lowest in 1999 and has kept growing since then.

**Figure 4.2: Evolution of share of non-state bank in total loan**



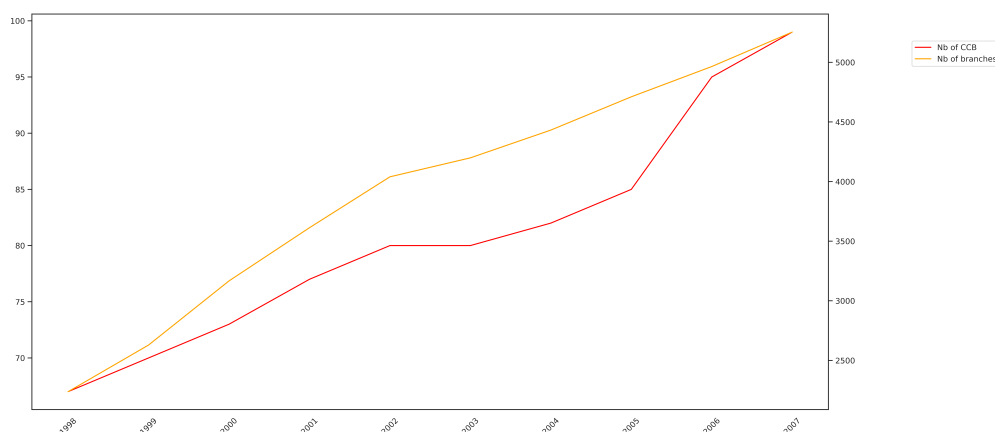
**Note:** The market share of non-SOBC is computed using the total loan provided by the 4 big states bank over the total credit. **Source:** Almanac of China's Finance and Banking

The key aspect of the commercial city bank is the plurality of the shareholder, which then leads to better corporate governance, and a lower control or interference from the government

<sup>5</sup>In comparison, Shanghai supplies about 47% in 2004, and the national average is 53%

in the bank's decision. The rise of commercial city banks began after 2000 (see figure 4.3) and, more importantly, after 2006, when the China Banking Regulatory Commission (CBRC) allowed city commercial banks to open other branches in other cities in their home province. In fact, in 2006, the CBRC stated that the twelve city commercial banks could apply to open a new branch in another city one at a time. The city commercial banks needed to wait for the result of the prior submission (approval or rejection) to submit another application. The process usually takes one year and more in some local CBRC offices.

**Figure 4.3: Expansion of city commercial banks from 1998 to 2007**



**Note:** The red line shows the number of unique city commercial branches. The yellow line shows the number of city commercial branches. **Source:** China Banking and Insurance Regulatory Commission

The successive waves of introduction into new types of financial institutions undeniably increased competition and spurred efficiency, especially in credit allocation. Unsurprisingly, the rate of NPL decreased subsequently by the end of 2002 (in response to the decreased market share of the SOBC). The liberalization and the reforms of the banking system have transformed the urban credit cooperative into commercial banks, which has allowed foreign banks, limited the state-centered management system, etc., and led to an improvement of China's financial landscape (better profitability and less risk).

The development of city commercial banks is a good indicator of the effort put in by the government to liberalize the Chinese banking system. In fact, the successive reforms reduced the degree of fragmentation of the banking system, which, in turn, proved helpful

for local-firm and small and medium companies. SMEs were a large recipient of loans from city commercial banks because they faced less discrimination to obtain a loan than applying in one of the "Big Four," which favor inefficient SOEs.

## 4.3 Financial development and emission of pollutants

### 4.3.1 China's banking system and the importance of environmental resolution

Considering the dominant position of bank credit in China's financing system, in 1995, the China Banking Regulatory Commission began introducing green financial regulatory policies based on international experiences<sup>6</sup> to gradually establish the environmental and social risk management system. In 1995, China's Environmental Protection Administration issued the first provision for a green financing initiative to aid the improvement of environmental quality. To achieve the binding target of reducing major pollutants' total emissions by 10% during the 11th Five-Year Plan period, the government further formulated concrete procedures and credit-issuing rules. In 2006, China launched its first green credit product-energy efficiency financing product and promised to adopt the *Equator Principles*,<sup>7</sup> a gold standard in the field of the international green credit system. In July 2007,<sup>8</sup> the State Environmental Protection Administration, the People's Bank of China, and the China Banking Regulatory Commission jointly issued guidelines on implementing environmental protection policies and

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<sup>6</sup>The International Finance Corporation (IFC), with the support of the Global Environment Foundation, Governments of Finland, Norway, and the Ministry of Finance of China designed the China Energy Conservation and Emission Reduction Financing Project (CHUEE) and created a loss-sharing business model to provide a loss sharing model in energy-saving and emission reduction related loans in cooperation with selected domestic, commercial banks. At the same time, it was decided that technical assistance will be provided to all parties involved in the project.

<sup>7</sup>The Equator principle is a "risk management framework, adopted by financial institutions, for determining, assessing, and managing environmental and social risk in projects, and is primarily intended to provide a minimum standard for due diligence and monitoring to support responsible risk decision-making." In 2021, seven Chinese banks became part of the Equator principal. Source: <https://equator-principles.com/about/>

<sup>8</sup>Source: [https://www.ifc.org/wps/wcm/connect/news\\_ext\\_content/ifc\\_external\\_corporate\\_site/news+and+events/news/china+takes+green+lending+to+a+new+level](https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/china+takes+green+lending+to+a+new+level)

regulations to prevent credit risks, thus imposing credit controls on enterprises and projects that do not adhere to industrial policies and violate environmental laws. Commercial banks also set stringent standards for environmental protection and regard enterprises' compliance with environmental laws as one of the necessary prerequisites for approving loans. According to statistics, in 2007, the four largest state-owned commercial banks (Industrial and Commercial Bank of China, Agricultural Bank of China, China Construction Bank, Bank of China, and Bank of Communications) issued a total of 106.334 billion yuan<sup>9</sup> of loans to support key projects of energy conservation and emissions' reduction in 2007. The introduction of "green credit"<sup>10</sup> has raised the threshold of enterprise loans in credit activities, environmental performance, and the capability of pollution abatement. Furthermore, ecological protection is regarded as an important prerequisite for credit approval. The green credit policy implemented by banks is beneficial for firms to internalize the cost of pollution and provide an important complement to controlling pollution emissions.

### **4.3.2 Diffusion channels between credit and emission of pollutants**

The effect of reforming the financial system has long been debated in the economic literature. Credit reforms not only enhance economic growth but also improve the allocation of resources across industries. More recently, the literature examined the effect of banking reforms on the emission of pollutants (Andersen 2016). Recent findings emphasize the possibility of three channels that affect firm environmental performances.

Firstly, a better allocation of credit can lower pollution levels by increasing investment in pollution abatement. Xu and Kim (2021) used a novel approach to evaluate credit constraints and found a positive association between financial constraints and the emission of toxic

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<sup>9</sup>Source: [http://www.gov.cn/govweb/jrzg/2008-02/26/content\\_901958.htm](http://www.gov.cn/govweb/jrzg/2008-02/26/content_901958.htm)

<sup>10</sup>According to the IFC, the "Green Credit Guidelines set out how banks should address sustainability issues at the board and top management level as well as how to integrate environmental and social considerations into the entire lending circle with a robust evaluation mechanism."

pollutants in the US. In a similar spirit, Goetz (2019) evaluates the impact of change in policy by the FED and concludes that exposure to a shock to long-term financing (reduction in the financing cost) prompts the treated firms to increase investment in capital-intensive pollution abatement and improve compliance with environmental regulation.

Secondly, cheaper access to external finance can increase investment in productivity-enhancing activities. In particular, when a firm has access to external finance, internal constraint becomes less of a burden. It potentially provides a financing alternative to invest in technology or equipment in order to increase productivity (Andersen 2017).

Finally, Andersen (2017) develops a theoretical model to demonstrate that credit constraint leads to investments in tangible assets as they are unable to finance intangible assets through a loan. He also shows that tangible assets have a positive relationship with pollutant emissions, concluding that financial constraint is detrimental to the environment.

## **4.4 Empirical strategy**

Our empirical strategy follows two steps: first, we evaluate how the development of credit conditions mitigates the emission of pollutants in the most financially vulnerable sectors. Second, we document the main mechanisms at stake to expound upon the manner in which the relocation of financial resources helped to reduce pollution emissions.

#### 4.4.1 Financial development and credit constraint

Our strategy evaluates whether the improvement of credit condition (as mentioned in section 4.3 via financial development) benefits the reduction in the emission of pollutants ( $SO_2$ , COD, or wastewater) in sectors characterized by different levels of financial vulnerability. Prior studies have proven that the lack of external funding (i.e., more resilient in the vulnerable sectors) is detrimental to growth, export productivity, and innovation (Jarreau and Poncet 2014; Li et al. 2018; Manova et al. 2015). Besides, both theoretical and empirical studies have exemplified the fact that the emission of pollutants is a function of firms' performances and innovations (Andersen 2016, 2017; Xu and Kim 2021). We contend that relaxing the credit constraint by improving access to the credit market leads firms to take a step forward in innovation and productivity, which, in turn, reduces the pollutant's per-unit level. The investment in technology adoption, pollution abatement equipment, or the rebalancing of the asset mix are the possible channels through which the effect between the improvement of financial development and emission reduction occurs.

We estimate the following equation through the period 1998 to 2007:

$$\begin{aligned} \text{Pollutant}_{ckt} = & \alpha_1 \text{Financial Dependencies}_k \times \text{Credit access}_{pt-1} + \\ & \alpha_2 \text{Financial Dependencies}_k \times \text{Bank deregulation}_{ct-1} + \\ & \beta X_{ckt} + \mu_{ct} + \gamma_{kt} + \delta_{ck} + \epsilon_{ckt} \end{aligned} \quad (4.1)$$

Where  $\text{Pollutant}_{ckt}$  denotes the level of  $SO_2$ , COD, or wastewater <sup>11</sup> in city  $c$ , for industry  $k$  and time  $t$ . The right-hand side of the equation comprises our main variables, a set of control variables, as well as fixed effects. We capture the industry's financial vulnerability with the indicator *Financial Dependencies* <sub>$k$</sub>  which is computed as the share of capital expenditure not financed out of cash flow from operation (Rajan and Zingales 1998). Larger values imply that the sector is more financially vulnerable. Our second variable is *credit access* <sub>$pt-1$</sub> ,

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<sup>11</sup> $SO_2$ , COD, and wastewater are the main pollutants in China

which is seen as exogenous by the firms and is typically controlled by bank policies. We measure credit access using credit availability in each province in China, one constructed at the province level. Specifically, we use the annual variation of external credit supply across different provinces and four municipalities in China computed as the share of the total loan, normalized by the province GDP (*Long-term loan*<sub>*pt-1*</sub>). Then, we use two proxies to capture *Bank deregulation*<sub>*ct-1*</sub> computed at the city level. Our first proxy is measured by the number of city commercial bank branches in year *t* in city *c*. Our second proxy is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Put succinctly, a decrease over time in the ratio implies more competition in the banking sectors and more credit supplied to the private sectors. *Credit access* and *Bank deregulation* are lagged by one year.

We add three control variables usually found in the literature (Andersen 2017; Maurel and Pernet 2020), which are the *total output*<sub>*ckt*</sub>, *total fixed asset*<sub>*ckt*</sub>, and *employment*<sub>*ckt*</sub> aggregated at the city *c*, industry *k* and time *t*. We also interact the GDP per capita with *Financial Dependencies*<sub>*k*</sub> to capture the fact that the financial system of richer cities might be more developed. We include the ratio FDI over population interacted with *Financial Dependencies*<sub>*k*</sub>. Foreign direct investments can potentially reduce the costs associated with the inefficient banking sector in China (Guariglia and Poncet 2008). The equation includes city-year fixed effect  $\mu_{ct}$ . It controls all city characteristics differing between cities through time, such as productivity, policies, and wages.  $\gamma_{kt}$  signifies an industry-time pair fixed effect that captures the intrinsic features of each industry within time, such as the technological contents and subsidies. With  $\delta_{ck}$ , we address the industry's invariant differences between cities. In our equation,  $\epsilon_{ckt}$  represents the error term.

The coefficients  $\alpha$  from both interaction terms are our coefficients of interest; we expect them to be negative and significant. The use of province-time and city-time variations to

evaluate the financial development along with banking deregulation in China, coupled with industrial-financial vulnerability, shows that for firms, improving the credit condition can be a mean of mitigating the emission of pollutants.

## 4.5 Data and variables construction

### 4.5.1 Emission of pollutant data sources

The Ministry of Environmental Protection (MEP) has been gathering the main data source of pollutants and wastes in China since 1980. The MEP has monitored firms in 39 major industrial sectors and considered heavy polluters. These firms are asked to report rudimentary information, such as company name, address, and output. They are also required to answer a detailed questionnaire about their emission of major pollutants (e.g., wastewater, COD,  $SO_2$ , industrial smoke, and dust). As reported in Wu et al. (2017) and Jiang et al. (2014), this dataset contains about 85% of the emission of pollution from major pollutants in China. To ensure that these firms have not misreported their emissions, the MEP has implemented strict procedures, including unforeseen expert visits. In our analysis, we have access to the  $SO_2$ , COD, and wastewater statistics, for 289 two digits industries spread across 284 cities from 1998 to 2007.

The primary air pollutant peaked in 2005 at 32.41 million tons of  $SO_2$  (figure 4.1). About 400 of the 522 cities monitored by the Chinese Ministry of Environment had annual average  $SO_2$  levels that meet the Grade II national standard ( $0.06\text{mg}/\text{m}^3$ )<sup>12</sup> and 33 cities met the

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<sup>12</sup>China uses its own air quality standard, which is less stringent than the WHO's standard. China's National Environmental Monitoring Center (CNEMC) has real-time, hourly air quality data for major cities in China. The real-time data is available here. Major air pollutants, including  $SO_2$ ,  $NO_2$ , and  $PM_{10}$  are monitored. To evaluate air quality, the Chinese government applies three classes. Class 1 means the yearly  $SO_2$  level is less than  $0.02\text{ mg}/\text{m}^3$ , or a daily average of less than  $0.05\text{mg}/\text{m}^3$ . On the other hand, Class 2



worst grade (0.10mg/m<sup>3</sup>). Two years after the 11th FYP was launched, the situation had changed slightly, according to the Ministry of Environment in its annual report on the state of the environment in China.<sup>13</sup> A total of 79% percent of the audited cities met Grade II, which is two percentage points higher than in 2005. A towering achievement concerning the Grade III criteria was that less than 1.2% of the cities went beyond the threshold, representing four percentage points less than in 2005. Shanxi, Guizhou, Inner Mongolia, and Yunnan provinces are the most polluted provinces.

#### 4.5.2 A measure of sector-level reliance on external finance

Firms must finance a fraction of the costs (fixed and variable) to meet the production level. We use the industry's external finance dependency, defined as the industry's exposure to the banks. The industry's external finance dependency computation is straightforward—it is the share of capital expenditure that is not financed with cash flow from operations. Previous works have used US data to proxy for exposure to external finance (Rajan and Zingales 1998; Claessens and Laeven 2003; Kroszner et al. 2007) and in the context of China (Jarreau and Poncet 2014; Manova et al. 2015; Fan et al. 2015). We use the Chinese data and replicate the methodology proposed by Fan et al. (2015), who utilized the ASIF dataset during 2004–2006 to aggregate the capital expenditure and cash flow at the two digits industrial level. Fan et al. (2015) argue that the financial pattern between the US and China is almost similar.<sup>14</sup> Tobacco is the least vulnerable sector in the US, while it ranks second in China. The leather products industry is the second least vulnerable in the US and the fifth least vulnerable in China. Table 4.9 in the appendix gives the value of financial dependence for the 29

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is less restrictive. The yearly average should not exceed 0.06 and a daily average of about 0.15. Class 3 is synonymous with poor air quality. The yearly average can exceed 0.10 mg/m<sup>3</sup>, and the daily average is 0.25. By contrast, the WHO recommends a daily average of less than 0.02mg/m<sup>3</sup>. For the records, exposure to high  $SO_2$  levels can inflict damage to health. According to the WHO, "  $SO_2$  can affect the respiratory system and the functions of the lungs and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma, and chronic bronchitis. It makes people more prone to respiratory tract infections."

<sup>13</sup>The report is available here: <http://english.mee.gov.cn/Resources/Reports/soe/soe2007/201>

<sup>14</sup>Unlike the US methodology, which uses the median over time, the authors use the aggregate value from the Chinese data because about 68% of the observations have 0 capital expenditure.

industries in China. The average value is  $-.57$ , with industries that have high technological requirements also being the most vulnerable. The *Petroleum* industry and *Processing of Nuclear Fuel* industries are at the bottom of the table, underscoring their high reliance on credit.

### 4.5.3 Financial development and banking deregulation

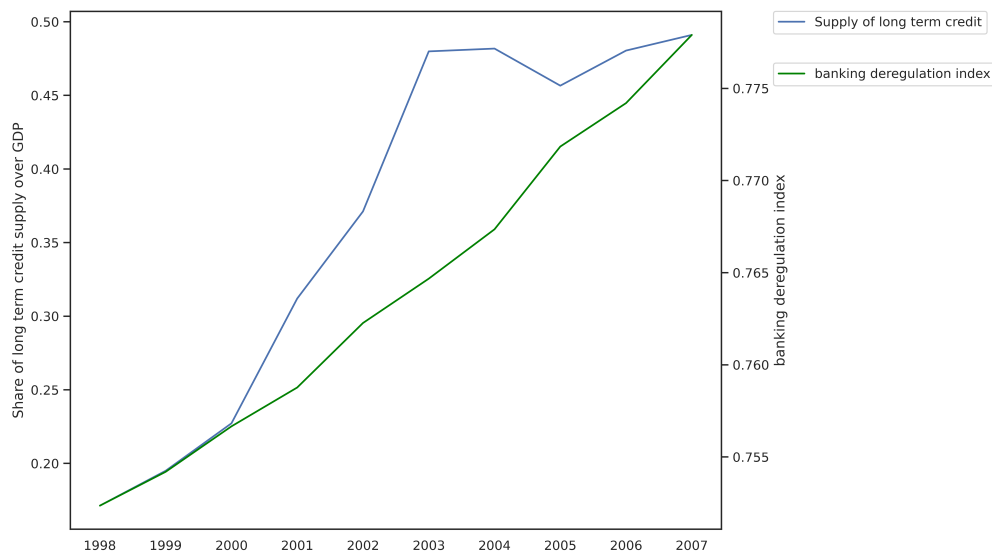
#### Credit access as a proxy for financial development

Four state banks mainly dominate the Chinese financial intermediation system. This domination leads to a distortion in capital allocation between private and SOE firms. Nevertheless, to reduce the predominance of the four state-owned banks and decrease the share of the non-profitable loan in the banks' balance sheets, China's banking system has undergone drastic deregulation. In our empirical strategy, we measure the financial development using the province's supply of long-term loans normalized by the GDP from 1998 to 2007. The data comes from the Almanac of China Finance and Banking. Overall, the credit supply has improved substantially, as emphasized in figure 4.4. In 1997, the average credit supply share was  $.15$  against  $.49$  in 2007. We observe substantial differences across areas in China. We use the classification of Wu et al. (2017) to label the provinces if they are located along the coast. During the period, the credit supply experienced a large inflow in provinces bordering the coast with an average credit supply over GDP of  $0.91$  ( $0.69$  in 1998) with a yearly average of  $4\%$ , while the other provinces increased the inflow from  $0.85$  to  $.90$  (yearly average of  $1.4\%$ ). The national average in 2007 was  $92\%$ , up from  $87\%$  in 1998. Unsurprisingly, municipal cities, such as Beijing, Shanghai, and the special economic zone of Shenzhen, usually enjoy better credit supplies than other provinces.

#### Bank deregulation and city commercial banks

Bank deregulation plays an important role in fostering competition between banks. Based on the number of city commercial branches and the local banks' market shares over the

**Figure 4.4: Evolution of share of long term credit supply over GDP and the bank deregulation index from 1997 to 2007**



**Note:** The long-term credit share is computed by dividing the total long-term loan normalized by the province GDP. The banking deregulation index is the inverse of the Herfindahl–Hirschman Index, a commonly accepted measure of market concentration.

**Source:** Almanac of China’s Finance and Banking and China Banking and Insurance Regulatory Commission

number of branches, we use two methods to measure the city-level bank competition.

First of all, we use the number of city commercial banks as a proxy for the liberalization of China’s local financial sector. The data comes from the website<sup>15</sup> of the China Banking and Insurance Regulatory Commission. According to Chaney (2016), an improved financial condition leads to better credit access through two channels: firstly, from a cheaper loan (lower interest rate), and secondly, through the supply of more credits. In the context of China, Chen et al. (2020) confirms the first channel but cannot conclude on the supply of more loans. Figure 4.3 illustrates both the expansion of the opening of city commercial banks as well as the creation of new entities from 1997 to 2007. The positive trend of the creation of new CCBs can be seen across China, albeit with some disparities in poorer provinces. In figure 4.5, we aggregate the number of new CCBs by province across time. Rich provinces

<sup>15</sup> <https://xkz.cbirc.gov.cn/jr/>



In a nutshell, we expect that the inflow of credit in the economy, through an improvement in financial intermediation (i.e., deregulation), leads to a larger reduction in pollution emissions in financially-constrained industries.

#### 4.5.4 City industry variables: control

Recent papers have demonstrated the role of the factors of production on environmental deterioration (Cole and Elliott 2003; Cole et al. 2008). Furthermore, capital intensity positively affects the emission and intensity of pollution (Hering and Poncet 2014; Andersen 2017). Moreover, large industries generate more  $SO_2$  emissions. The National Bureau of Statistics of China (NBS) gathers manufacturing data for all non-state-owned-enterprise with sales above RMB 5 million and state-owned-enterprise (SOEs). The survey contains detailed information about the name, address, four-digit CIC industry classification, ownership, as well as financial variables, including output, sales, and fixed assets. This dataset is reliable for at least two reasons. First, since 1995 the NBS has used the firms' survey data to compute metrics such as GDP. Second, firms do not have incentives to misreport the numbers. According to Chen et al. (2018), the NBS is disallowed from sharing information with other agencies (e.g., tax agencies, government, etc.). The NBS uses its industrial classification to sort firms by sector. Since our data started in 1998 and ended in 2007, we can use the 2002 GBT classification for each year of our sample data. The financial dependency variable is computed at the two-digit industrial level. All of the industrial variables are computed at the two digits classification to stay consistent with the financial dependency variable. We aggregate the total output by year and city for all the two-digit industries. Furthermore, we compute the total employment at the city-industry-year level. Finally, the ASIF dataset gives firms' yearly total net fixed assets. We use this information to compute the city-industry-year total fixed asset.

## 4.6 Empirical results

This section presents the main results about the linkage between financial development and the emission of pollutants. We use the annual provincial credit supply normalized by GDP as a proxy for credit supply (credit access); we also use two proxies for financial liberalization: 1. the total number of city branches; 2. the inverse of the Herfindahl-Hirschman Index (HHI). We then interact credit access/deregulation with the exogenous variable capturing credit constraint to evaluate the differential effect of the financial distress on the emission of pollutants. We aimed to demonstrate that financial development is more beneficial for sectors relying on external finances, reducing pollution emissions.

### 4.6.1 Main results: the relationship between financial development and pollution emission

Table 4.1 reports results of equation 4.1 for the three main pollutants investigated,  $SO_2$ , COD, and wastewater. Columns 1 and 2 of table 4.1 report the coefficients for the  $SO_2$  pollutant, columns 3 and 4 report the COD coefficients, and the last two columns for the wastewater. Odd columns interact *credit constraint* with the *number of city branches*, and even columns interact *credit constraint* with *bank competition*. All columns include the interaction with *credit constraint* and *long term loan*. All results are negative and significant, except for the  $SO_2$  pollutant.<sup>16</sup> It confirms our initial hypothesis that an improvement of the credit market condition reduces the emission of pollutants.

According to the extant literature, developing a better financial market (equity or credit) involves substantial investments toward greener technologies given that the pool of external financing is larger (De Haas and Popov 2018). Financial development can also facilitate

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<sup>16</sup>The number of observations is different by pollutant as some information is missing at the city-industry-year level

**Table 4.1: Pollution emissions, credit access and banking deregulation**

|   | Dependent variable:  |                      |                     |                     |                      |                      |
|---|----------------------|----------------------|---------------------|---------------------|----------------------|----------------------|
|   | $SO_2$               |                      | COD                 |                     | Waste water          |                      |
|   | (1)                  | (2)                  | (3)                 | (4)                 | (5)                  | (6)                  |
| <i>Credit access</i>                                      |                      |                      |                     |                     |                      |                      |
| Long-term loan $_{pt-1}$ $\times$ credit constraint       | -0.470***<br>(0.153) | -0.441***<br>(0.152) | -0.303*<br>(0.179)  | -0.383**<br>(0.178) | -0.483***<br>(0.157) | -0.538***<br>(0.156) |
| <i>Banking deregulation</i>                               |                      |                      |                     |                     |                      |                      |
| No. of city branches $_{ct-1}$ $\times$ credit constraint | 0.001<br>(0.001)     |                      | -0.003**<br>(0.001) |                     | -0.002**<br>(0.001)  |                      |
| Bank competition $_{ct-1}$ $\times$ credit constraint     |                      | 0.530<br>(0.513)     |                     | -1.55***<br>(0.592) |                      | -1.06**<br>(0.528)   |
| <i>Control variables</i>                                  |                      |                      |                     |                     |                      |                      |
| log(output)   | 0.036**<br>(0.018)   | 0.035**<br>(0.018)   | 0.107***<br>(0.021) | 0.107***<br>(0.021) | 0.065***<br>(0.018)  | 0.065***<br>(0.018)  |
| log(employment)   | 0.220***<br>(0.021)  | 0.220***<br>(0.021)  | 0.224***<br>(0.025) | 0.223***<br>(0.025) | 0.266***<br>(0.021)  | 0.266***<br>(0.021)  |
| log(capital)  | 0.010<br>(0.014)     | 0.010<br>(0.014)     | -0.010<br>(0.017)   | -0.009<br>(0.017)   | 0.023<br>(0.014)     | 0.023<br>(0.014)     |
| log(gdp / pop) $\times$ credit constraint                 | 0.177***<br>(0.067)  | 0.181***<br>(0.067)  | 0.067<br>(0.079)    | 0.056<br>(0.079)    | 0.190***<br>(0.068)  | 0.182***<br>(0.068)  |
| log(FDI / gdp) $\times$ credit constraint                 | -0.026**<br>(0.013)  | -0.025**<br>(0.013)  | 0.015<br>(0.015)    | 0.013<br>(0.015)    | -0.018<br>(0.013)    | -0.020<br>(0.013)    |
| City-industry   | Yes                  | Yes                  | Yes                 | Yes                 | Yes                  | Yes                  |
| Time-industry   | Yes                  | Yes                  | Yes                 | Yes                 | Yes                  | Yes                  |
| City-Time   | Yes                  | Yes                  | Yes                 | Yes                 | Yes                  | Yes                  |
| Observations  | 39,326               | 39,326               | 37,908              | 37,908              | 41,120               | 41,120               |
| R <sup>2</sup>  | 0.844                | 0.844                | 0.832               | 0.832               | 0.844                | 0.844                |

This table reports estimates of equation 4.1. All of the three dependent variables are in the log. *Financial Dependenc<sub>k</sub>*, which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan $_{pt-1}$  is the share of the total loan normalized by the province GDP; No. of city branches $_{ct-1}$  denotes the number of city commercial bank branches; Bank competition $_{ct-1}$  represents the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

the incorporation of state-of-the-art technologies and the purchase of pollution abatement equipment (Xu and Kim 2021; Goetz 2019). More recently, Levine et al. (2018) shows that positive shocks to credit conditions reduce corporate pollution.

More specifically, the coefficient from the credit supply captures the pollution elasticities in sectors that are more or less constrained. The negative sign implies that an inflow of credit on the market has a substantial impact on the pollution of the sectors in financial distress. Access to credit enables the private sector to invest in productivity-enhancing activities, research and development, or pollution abatement equipment to maintain their operation. The interaction terms from the banking deregulation variables and credit constraint are all negative and significant for COD and wastewater with a roughly similar magnitude,  $-.003$  for COD and  $-.002$  for wastewater for the coefficient of the number of city commercial banks. The coefficients for the bank competition proxy by the inverse of the HHI index are equal to  $-1.55$  for the COD and  $-1.06$  for the wastewater significant at 1% for the former and 5% for the latter. We cannot conclude a relationship between bank deregulation and  $SO_2$  emissions.

#### **4.6.2 Heterogeneous effect**

We have provided evidence of the average effect of financial reliance on external credit on the emission of pollutants ( $SO_2$ , COD, and wastewater). In this section, we investigate whether this average effect differs based on industrial pollution intensity.

##### **Industry heterogeneity: polluted *versus* less polluted sectors**

In this section, we investigate the heterogeneous effect of financial development and bank deregulation on the emission of different pollutants according to the polluting severity of a sector. We use the nomenclature of He et al. (2020) to classify the sectors into two sectors:



polluting and less polluting. According to the author, the 16 polluting industries defined by the MEP comprise roughly 80% of China's total industrial COD emissions. Odd columns estimate equation 4.1 using the polluting sectors sub-sample, and even columns use the less-polluting sectors. Columns 1 to 4 in table 4.2 display the results for the  $SO_2$  emissions, columns 5 to 8 correspond to the COD emissions, whereas the last four columns refer to the wastewater emissions. Results for  $SO_2$  emissions are in consonance with the baseline regression (table 4.1), that banking deregulation has no impact on the  $SO_2$  emissions, even after splitting the industries into two sectors. All sample regression results for the COD and wastewater emissions imply that banking deregulation plays a positive role only in constrained firms in less polluting industries. Banks are asked to reduce and even cut off loans to polluting firms, which can explain why deregulation does not impact the emission of pollution. If the firms are banned from the credit market, they cannot use external funds to invest or buy assets to maintain production. Another explanation could be that banks have always provided large industrial firms with credit to promote industrialization while paying little attention to the environment (The World Bank 2008). Therefore, in both scenarios, cutting off credit to polluting firms or financing industrialization in polluted sectors might not be helpful in achieving the objectives of pollution emissions observed in the 10th and 11th Five-Year-Plan.<sup>17</sup>

## 4.7 Mechanisms between financial development and pollution emissions

We leverage the richness of the MEP dataset to examine the underlying mechanisms between financial development and pollution emissions. As emphasized in section 4.3, three mechanisms can potentially affect pollution emissions. Firstly, the purchase of pollution abatement

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<sup>17</sup>In the 10th FYP, a national objective of a 10% reduction of  $SO_2$  emissions was established. By the end of 2005, a decision was taken to enforce the 10% mandate in the framework of the 11th FYP, and more constraints were put in place at the local level.

**Table 4.2: Emission of pollutions and polluting severity of a sector**

|   | Dependent variable:  |                     |                      |                     |                      |                     |                      |                     |                     |                     |                     |                     |
|---|----------------------|---------------------|----------------------|---------------------|----------------------|---------------------|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|   | $SO_2$               |                     |                      | COD                 |                      |                     | Waste water          |                     |                     |                     |                     |                     |
|   | (1)                  | (2)                 | (3)                  | (4)                 | (5)                  | (6)                 | (7)                  | (8)                 | (9)                 | (10)                | (11)                | (12)                |
| PI  | LPI                  | PI                  | LPI                  | PI                  | LPI                  | PI                  | LPI                  | PI                  | LPI                 | PI                  | LPI                 | PI                  |
| <i>Credit access</i>                                    |                      |                     |                      |                     |                      |                     |                      |                     |                     |                     |                     |                     |
| Long-term loan $_{pt-1} \times$ credit constraint       | -0.979***<br>(0.336) | -0.434**<br>(0.180) | -0.962***<br>(0.334) | -0.402**<br>(0.179) | -0.826*<br>(0.430)   | -0.181<br>(0.205)   | -0.846**<br>(0.428)  | -0.265<br>(0.204)   | -0.871**<br>(0.341) | -0.408**<br>(0.184) | -0.867**<br>(0.339) | -0.463**<br>(0.183) |
| <i>Banking deregulation</i>                             |                      |                     |                      |                     |                      |                     |                      |                     |                     |                     |                     |                     |
| No. of city branches $_{ct-1} \times$ credit constraint | 0.0007<br>(0.002)    | 0.001<br>(0.001)    |                      |                     | 0.0006<br>(0.003)    | -0.003**<br>(0.001) |                      |                     | 0.0006<br>(0.002)   | -0.002**<br>(0.001) |                     |                     |
| Bank competition $_{ct-1} \times$ credit constraint     |                      |                     | 0.270<br>(1.13)      | 0.643<br>(0.600)    |                      |                     | -1.75<br>(1.38)      | -1.47**<br>(0.679)  |                     |                     | -0.477<br>(1.11)    | -1.04*<br>(0.618)   |
| <i>Control variables</i>                                |                      |                     |                      |                     |                      |                     |                      |                     |                     |                     |                     |                     |
| log(output)   | 0.011<br>(0.032)     | 0.057**<br>(0.022)  | 0.011<br>(0.032)     | 0.057**<br>(0.022)  | 0.103**<br>(0.041)   | 0.122***<br>(0.026) | 0.105***<br>(0.041)  | 0.122***<br>(0.026) | 0.060*<br>(0.032)   | 0.070***<br>(0.022) | 0.060*<br>(0.032)   | 0.070***<br>(0.022) |
| log(employment)   | 0.172***<br>(0.038)  | 0.228***<br>(0.026) | 0.172***<br>(0.038)  | 0.229***<br>(0.026) | 0.139***<br>(0.048)  | 0.245***<br>(0.031) | 0.137***<br>(0.048)  | 0.244***<br>(0.031) | 0.177***<br>(0.038) | 0.294***<br>(0.026) | 0.176***<br>(0.038) | 0.294***<br>(0.026) |
| log(capital)  | 0.018<br>(0.025)     | 0.004<br>(0.017)    | 0.018<br>(0.025)     | 0.004<br>(0.017)    | 0.019<br>(0.032)     | -0.021<br>(0.021)   | 0.018<br>(0.032)     | -0.020<br>(0.021)   | 0.046*<br>(0.025)   | 0.009<br>(0.018)    | 0.046*<br>(0.025)   | 0.010<br>(0.018)    |
| log(gdp / pop) $\times$ credit constraint               | 0.025<br>(0.163)     | 0.193**<br>(0.077)  | 0.028<br>(0.163)     | 0.197**<br>(0.077)  | 0.266<br>(0.212)     | 0.047<br>(0.089)    | 0.273<br>(0.211)     | 0.035<br>(0.089)    | 0.104<br>(0.166)    | 0.223***<br>(0.078) | 0.108<br>(0.166)    | 0.213***<br>(0.078) |
| log(FDI / gdp) $\times$ credit constraint               | -0.108***<br>(0.030) | -0.014<br>(0.015)   | -0.107***<br>(0.030) | -0.013<br>(0.015)   | -0.128***<br>(0.040) | 0.038**<br>(0.018)  | -0.129***<br>(0.040) | 0.035**<br>(0.018)  | -0.075**<br>(0.031) | -0.008<br>(0.015)   | -0.075**<br>(0.031) | -0.010<br>(0.015)   |
| City-industry   | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                 | Yes                 | Yes                 | Yes                 |
| Time-industry   | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                 | Yes                 | Yes                 | Yes                 |
| City-Time   | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                  | Yes                 | Yes                 | Yes                 | Yes                 | Yes                 |
| Observations  | 10,803               | 28,523              | 10,803               | 28,523              | 10,522               | 27,386              | 10,522               | 27,386              | 10,867              | 30,253              | 10,867              | 30,253              |
| R <sup>2</sup>  | 0.900                | 0.807               | 0.900                | 0.807               | 0.852                | 0.828               | 0.852                | 0.828               | 0.892               | 0.828               | 0.892               | 0.828               |

This table reports estimates of equation 4.1. All of the three dependent variables are in log. *Financial Dependences<sub>k</sub>*, which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan $_{pt-1}$  signifies the share of the total loan normalized by the province GDP; No. of city branches $_{ct-1}$  denotes the number of city commercial bank branches; Bank competition $_{ct-1}$  is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. The nomenclature to classify the sectors into polluting and less polluting sectors come from He et al. (2020). Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

equipment can be used to reduce emissions. Secondly, investment in better technology, and lastly, an improvement of the asset mix or a reduction in production, can also affect pollution emissions.

#### **4.7.1 Pollution abatement equipment and technology adoption**

Financial development is characterized by cheaper access to credit and a larger inflow of money, as explicated by Chaney (2016). In both cases, it can be argued that more credit supply or easier access to a loan can be used to buy pollution abatement equipment. The government has also urged banks to lend to environmental-compliant firms.

In this context, a firm can choose to invest in capital-intensive pollution abatement or technology adoption. So far, it is unclear which effect dominates from a theoretical point of view and if either effect has a statistical impact on emissions. The effect is nebulous because cheaper access to finance might lead firms to increase their investments in pollution abatement equipment. However, if a firm decides to invest in technology adoption that spurs productivity, it reduces energy consumption because of a per unit cost-saving. The technology-adoption channel reduces pollution emissions, which, to some extent, minimizes the incentive for a firm to purchase pollution abatement equipment. In the context of developed economies, Goetz (2019) shows that an exogenous financial shock positively affecting the access to finance led US firms to cut pollutant discharge through pollution abatement. By contrast, in the context of developing economies, Gutiérrez and Teshima (2018) demonstrate that the reduced pollution emissions come from the technology-adoption mechanism. To test the first channel (i.e., purchase of pollution abatement equipment), we use two different proxies available in the MEP dataset. Firms are asked to report the stock of  $SO_2$  and wastewater pollution abatement. We use this information at the city-industry-year level. We also use industrial water consumption in the production process to assess the technology-related channel. Firms can bring down their emissions through a cost-saving process improvement using technology upgrading or better management practice without

purchasing pollution abatement equipment (Gutiérrez and Teshima 2018). To measure the improvement in plants' general technology, we follow Gutiérrez and Teshima (2018) and divide the total use of industrial water over sales. The variable suggests that the production efficiency of industries with lower values is better.

### **Pollution abatement equipment**

Table 4.3 reports the results of the purchase of pollution abatement equipment. Columns 1 and 2 illustrate the results for the  $SO_2$  equipment, and columns 3 and 4 display the wastewater equipment. For example, to abate COD discharges at the end of the pipe, firms typically need to install a wastewater treatment system that includes aeration tanks and air flotation devices. According to the results, more financially-constrained firms do not contribute to the changes in pollution emissions by purchasing pollution abatement equipment. One plausible explanation could be that when confronted with financial constraints, managers de-prioritize environmental abatement. Acquiring such equipment does not affect productivity or improve sales. Instead, it adds an incremental cost of production. Specifically, the price of pollution abatement equipment is high and potentially beyond reach for constrained or small firms. Data about the pollution abatement equipment investment in China is unavailable, but in the US, manufacturers spent over 26.57 billion on equipment in 2005, accounting for more than 20% of the total capital expenditure (Goetz 2019).

Another plausible explanation can originate from the lack of environmental law enforcement. Recent studies in China (Chen et al. 2018; He et al. 2020) and in the US (Evans and Stafford 2019; Goetz 2019; Karpoff et al. 2005; Shapira and Zingales 2017) have documented the role of environmental compliance in the behavior of a firm. If the environmental law enforcement is not strong, and the likelihood of receiving a fine (or a modest fine) is low to some extent, then a firm does not have much incentive to invest heavily in pollution abatement equipment. We test the environmental law enforcement hypothesis in table 4.4. Chinese policymakers decided to take the environmental issue seriously after the sulfur

**Table 4.3: Pollution abatement equipment and pollution emissions**

|   | Dependent variable: |                       |                   |                   |
|---|---------------------|-----------------------|-------------------|-------------------|
|   | $SO_2$ equipment    | Waste water equipment |                   |                   |
|   | (1)                 | (2)                   | (3)               | (4)               |
| <i>Credit access</i>                                      |                     |                       |                   |                   |
| Long-term loan $_{pt-1}$ $\times$ credit constraint       | -1.28<br>(2.55)     | -1.15<br>(2.60)       | 0.261<br>(3.73)   | 0.503<br>(3.78)   |
| <i>Banking deregulation</i>                               |                     |                       |                   |                   |
| No. of city branches $_{ct-1}$ $\times$ credit constraint | 0.007<br>(0.009)    |                       | 0.007<br>(0.021)  |                   |
| Bank competition $_{ct-1}$ $\times$ credit constraint     |                     | -0.376<br>(1.07)      |                   | 6.39<br>(4.88)    |
| <i>Control variables</i>                                  |                     |                       |                   |                   |
| log(output)   | 0.043<br>(0.053)    | 0.043<br>(0.053)      | 0.443<br>(0.363)  | 0.441<br>(0.364)  |
| log(employment)   | 0.444***<br>(0.107) | 0.444***<br>(0.108)   | 0.817<br>(0.492)  | 0.820<br>(0.494)  |
| log(capital)  | -0.112*<br>(0.057)  | -0.112*<br>(0.057)    | 0.200<br>(0.184)  | 0.198<br>(0.184)  |
| log(gdp pop) credit constraint                            | 0.354<br>(0.540)    | 0.392<br>(0.544)      | -0.339<br>(0.943) | -0.319<br>(0.985) |
| log(FDI / gdp) $\times$ credit constraint                 | -0.178**<br>(0.074) | -0.175**<br>(0.078)   | -0.219<br>(0.175) | -0.212<br>(0.181) |
| City-industry   | Yes                 | Yes                   | Yes               | Yes               |
| Time-industry   | Yes                 | Yes                   | Yes               | Yes               |
| City-Time   | Yes                 | Yes                   | Yes               | Yes               |
| Observations  | 39,326              | 39,326                | 41,120            | 41,120            |
| R <sup>2</sup>  | 0.652               | 0.652                 | 0.653             | 0.653             |

$SO_2$  and wastewater equipment come from the MEP dataset. They inform about the stock of pollution abatement equipment.  $Financial\ Dependencies_k$  which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan $_{pt-1}$  denotes the share of the total loan normalized by the province GDP; No. of city branches $_{ct-1}$  signifies the number of city commercial bank branches; Bank competition $_{ct-1}$  is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

dioxide ( $SO_2$ ) peak inflicted damage upon the country in 1995. In no less than three years, the officials in Beijing proposed and ratified a law regulating  $SO_2$  emissions. In 1998, the central government implemented the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone policy, abbreviated as the Two Control Zone (TCZ) policy, to limit pollutant emissions. While the regulation of  $SO_2$  emissions was initially designed to be implemented across the nation, the State Council subsequently chose 175 TCZ cities with very poor environmental records to engage with more effort. Three selection criteria were chosen based on pre-regulation environmental performance. A city was scrutinized if the average annual ambient  $SO_2$  concentration exceeded the national class 2 standard (0.06mg/m<sup>3</sup>), if the daily average ambient  $SO_2$  concentration exceeded the national class3 standard (0.25mg/m<sup>3</sup>), or if the city witnessed significant  $SO_2$  emissions.

We extend equation 4.1 by interacting *Credit access* and *Bank deregulation* with a dummy variable taking the value of 1 if the city is targeted by the environmental policy with the sectorial *financial dependencies*. We expect the triple interaction term coefficient to be negative for the  $SO_2$  equipment. Results are displayed in table 4.4. The coefficients on the triple interaction with financial development and TCZ cities are negative and significant. The long-term loan supply is only available at the provincial level, which includes a mix of cities targeted or not by the policy, which can explain the positive sign. However, upon interacting TCZ with the bank deregulation, which is calculated at the city level, we found a negative and significant coefficient. These results indicate that unforeseen visits and stronger regulatory scrutiny by the regulator impel firms to invest in pollution abatement equipment in more financially constrained sectors (columns 1 and 2). We run a placebo test in columns 3 and 4 using wastewater equipment instead of  $SO_2$  equipment. TCZ-targeted cities are intended to put more effort into  $SO_2$  emissions. Therefore, the policy might not affect the other pollutants. We found a positive but insignificant effect of a stringent environmental policy affecting  $SO_2$  emissions on the purchase of wastewater equipment. These results indicate that the behavior of firms adjusts when they are impacted by an environmental policy.

This behavioral change is specific to the design and objective of the policy; in the Chinese context, the reduction of  $SO_2$  emissions in targeted cities.

### **Technology adoption**

Our second mechanism testing comes with estimating the technology adoption argument after an improvement of the financial condition. Cheaper and easier access to finance leads firms to invest in technology that is capable of altering the production process, affecting both productivity and energy consumption. Those investments are likely to reduce manufacturing costs and improve technical efficiency. We utilize the firm's total usage of industrial water resources over the sales to estimate the energy efficiency as in Gutiérrez and Teshima (2018). A lower value of the ratio indicates better production efficiency. Table 4.5 shows the results of the technology adoption hypothesis. Columns 1 and 2 display negative and significant coefficients for both the supply of credit and bank deregulation, suggesting that financial development increases energy efficiency in sectors that are financially constrained. The results complement the findings of Gutiérrez and Teshima (2018) that show firms reduce their energy consumption through technology adoption following stronger bank competition. In the appendix, we validate our results using firms' level data. We use the sewage charges as a proxy for technology adoption. Sewage costs are calculated based on firm-generated wastewater. A larger amount of sewage costs implies that the plant produces more wastewater and/or uses more clean water in the production process. When a firm is charged more for treating sewage, it implies a less-efficient production practice, controlling for the output. Notably, both coefficients are negative and significant, controlling for internal finance (cash flow and current ratio) and the age, export, employment, capital, and output.

In a nutshell, our results have varied implications for policymakers. Firstly, we show that financial development alone will not trigger a reduction in pollution emissions through the purchase of pollution abatement equipment. One plausible reason could be the large sunk cost it implies or the integration of law enforcement in the firm's behavior. The environmental

**Table 4.4: Pollution abatement equipment, pollution emissions and environmental policy**

|  | Dependent variable: |                     |                   |                    |
|--|---------------------|---------------------|-------------------|--------------------|
|  | $SO_2$ equipment    |                     | COD equipment     |                    |
|  | (1)                 | (2)                 | (3)               | (4)                |
| <i>Credit access</i>   |                     |                     |                   |                    |
| Long-term loan $_{pt-1}$ $\times$ credit constraint                    | -0.750<br>(2.53)    | -0.883<br>(2.76)    | -5.16<br>(5.04)   | -4.87<br>(5.05)    |
| Long-term loan $_{pt-1}$ $\times$ credit constraint $\times$ tcz       | -3.32**<br>(1.25)   | -3.07**<br>(1.34)   | 5.16<br>(3.08)    | 5.66<br>(4.36)     |
| <i>Banking deregulation</i>  |                     |                     |                   |                    |
| No. of city branches $_{ct-1}$ $\times$ credit constraint              | 0.001<br>(0.008)    |                     | -0.089<br>(0.112) |                    |
| No. of city branches $_{ct-1}$ $\times$ credit constraint $\times$ tcz | 0.031**<br>(0.011)  |                     | 0.104<br>(0.113)  |                    |
| Bank competition $_{ct-1}$ $\times$ credit constraint                  |                     | -1.79<br>(1.65)     |                   | -17.6<br>(20.3)    |
| Bank competition $_{ct-1}$ $\times$ credit constraint $\times$ tcz     |                     | 6.42***<br>(2.26)   |                   | 32.1<br>(23.1)     |
| <i>Control variables</i>   |                     |                     |                   |                    |
| log(output)  | 0.043<br>(0.053)    | 0.043<br>(0.056)    | 0.429<br>(0.362)  | 0.429<br>(0.355)   |
| log(employment)  | 0.445***<br>(0.107) | 0.444***<br>(0.108) | 0.819<br>(0.495)  | 0.826**<br>(0.414) |
| log(capital)   | -0.112*<br>(0.056)  | -0.112*<br>(0.057)  | 0.207<br>(0.186)  | 0.206<br>(0.280)   |
| log(gdp / pop) $\times$ credit constraint                              | 0.399<br>(0.530)    | 0.421<br>(0.570)    | -0.367<br>(1.02)  | -0.374<br>(1.35)   |
| log(FDI / gdp) $\times$ credit constraint                              | -0.184**<br>(0.075) | -0.178*<br>(0.097)  | -0.204<br>(0.180) | -0.208<br>(0.259)  |
| City-industry  | Yes                 | Yes                 | Yes               | Yes                |
| Time-industry  | Yes                 | Yes                 | Yes               | Yes                |
| City-Time  | Yes                 | Yes                 | Yes               | Yes                |
| Observations   | 39,326              | 39,326              | 41,120            | 41,120             |
| R <sup>2</sup>   | 0.652               | 0.652               | 0.653             | 0.876              |

$SO_2$  and wastewater equipment come from the MEP dataset. They inform about the stock of pollution abatement equipment.  $Financial\ Dependencies_k$  which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan $_{pt-1}$  is the share of the total loan normalized by the province GDP; No. of city branches $_{ct-1}$  is the number of city commercial bank branches; Bank competition $_{ct-1}$  is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. TCZ is cities targeted by the government with very poor environmental performance. The State Council provides the list of TCZ in 1998. "Official Reply to the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas". Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%



**Table 4.5: Technology adoption and pollution emissions**

|  | Dependent variable: Water consumption intensity |                      |
|--|---|----------------------|
|  | (1)   | (2)                  |
| <i>Credit access</i>                                     |   |                      |
| Long-term loan <sub>pt-1</sub> × credit constraint       | -0.308*<br>(0.174)                              | -0.353*<br>(0.174)   |
| <i>Banking deregulation</i>                              |   |                      |
| No. of city branches <sub>ct-1</sub> × credit constraint | -0.001*<br>(0.0008)                             |                      |
| Bank competition <sub>ct-1</sub> × credit constraint     |   | -1.04***<br>(0.358)  |
| <i>Control variables</i>                                 |   |                      |
| log(output)  | -0.859***<br>(0.030)                            | -0.859***<br>(0.030) |
| log(employment)  | 0.186***<br>(0.037)                             | 0.186***<br>(0.038)  |
| log(capital)   | -0.004<br>(0.015)                               | -0.004<br>(0.015)    |
| log(gdp / pop) × credit constraint                       | 0.138<br>(0.101)                                | 0.134<br>(0.102)     |
| log(FDI / gdp) × credit constraint                       | 0.011<br>(0.012)                                | 0.009<br>(0.012)     |
| City-industry  | Yes   | Yes                  |
| Time-industry  | Yes   | Yes                  |
| City-Time  | Yes   | Yes                  |
| Observations   | 37,904  | 37,904               |
| R <sup>2</sup>   | 0.847   | 0.847                |

The dependent variables come from the MEP dataset. It is constructed using the industrial water consumption divided by the sales as in Gutiérrez and Teshima 2018. The log of *water consumption intensity* is used. A lower value of the ratio is indicative of a better production efficiency. *Financial Dependences<sub>k</sub>* which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan<sub>pt-1</sub> denotes the share of the total loan normalized by the province GDP; No. of city branches<sub>ct-1</sub> is the number of city commercial bank branches; Bank competition<sub>ct-1</sub> signifies the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

policy complements financial development when the former is designed for specific purposes. While firms manufacturing goods in financially constrained industries located in TCZ cities have increased their stock of  $SO_2$  pollution abatement equipment, the fact remains that they have no effect on purchasing wastewater, implying that the firm's behavior follows the policy's objective. Secondly, we argue that cheaper and easier access to finance spurs the investment of firms that improve technical efficiency leading to a reduction in energy consumption. The adoption of new technology lowers emissions without investment in pollution abatement. Firms will prefer investing in novel technologies because this translates into increased sales. Conversely, investments in pollution abatement have no impact on sales, while they increase fixed costs.

#### **4.7.2 Asset mix and scale effect**

Asset distortion can play a role in pollution emissions. Andersen (2017) built a model where the credit institution indirectly impacts pollution emissions. He shows that constrained firms typically finance tangible assets through a loan because banks require collateral as a security. By extension, the distortion of asset allocation toward tangible assets has a positive correlation with pollution emissions. By relaxing the credit constraint, firms could re-balance the type of asset they hold and invest relatively less in tangible and more in intangible. In this situation, it should reduce pollution emissions.

There is another way whereby relaxing credit constraints could contribute to pollution emissions. Fazzari et al. (1988) mentioned that cheaper access to finance could increase both investments and production, and we would see an increase in pollution emissions without a change in the production process. The increased production scale may impose greater stress on the environment because, assuming the constant technique effect, more inputs and resources are required to satisfy the increased demand.

We test both mechanisms through equations 4.3 and 4.4. To estimate both equations, we exploit the richness of the ASIF firm-level data from the NBS. Equation 4.3 hypothesizes

that asset mix (tangible *versus* intangible) is affected by the financial development proxy by credit supply or the banking deregulation. Equation 4.4 evaluates the scale effect where cheaper and easier credit increases production.

### Asset mix

Equation 4.3 investigates the possible linkage between financial development and the asset mix. Banks tend to fund tangible assets due to the availability of collateral as a security that can be sold in the market in case of default on loans. An improvement of the financial condition in the credit market can increase the investment of intangible assets (i.e., reduce the asset tangibility ratio), thus reducing pollution emissions. We test this hypothesis in equation 4.3.

$$\begin{aligned} \text{Asset mix}_{fckt} = & \alpha_0 \text{Credit access}_{pt-1} + \alpha_1 \text{Financial Dependencies}_k \times \text{Credit access}_{pt-1} + \\ & \alpha_2 \text{Bank deregulation}_{ct-1} + \alpha_3 \text{Financial Dependencies}_k \times \text{Bank deregulation}_{ct-1} + \\ & \beta_4 X_{fckt} + \beta_5 X_{ckt} + \mu_f + \gamma_t + \delta_c + \epsilon_{fckt} \end{aligned} \tag{4.3}$$

Where *asset mix<sub>fckt</sub>* in equation 4.3 refers to the share of asset tangibility over total assets. *Credit access* is a proxy for the supply of long-term credit available at the province *p* level, and *bank deregulation* is a proxy with the number of city branches and the inverse of the HHI. The two latter variables are computed at the city level. Larger values imply less regulation and more competition across banks. We downloaded the data from China Banking and Insurance Regulatory Commission<sup>18</sup> to construct the number of city branches and bank competition. We interact the provincial credit supply, number of city branches, and bank deregulation with a financial constraint index, which is computed as the share of capital expenditure not financed out of cash flow from operation (Rajan and Zingales 1998). There are two sets of control variables. The first set of variables is available at the city-

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<sup>18</sup>data available here <https://xkz.cbirc.gov.cn/jr/>

year level, while the second set is available at the firm level. We control for macroeconomic conditions using the GDP per capita or the ratio of FDI over GDP, since FDI may be used to mitigate the costs associated with the inefficient banking sector in China (Guariglia and Poncet (2008)).  $X_{fct}$  includes usual controls found in the literature, namely *cash flow* $_{fct}$  and *current ratio* $_{fct}$ , *liabilities to assets*, *output*, *employment*, *capital*, *age* and *export to sale*. The inclusion of industry and time ( $\gamma_i, \gamma_t$ ) fixed effects removes the trends associated with all firms in a particular industry. Finally, entering firm fixed effects ( $\zeta_f$ ) removes all unobserved factors that contribute to a firm's asset accumulation within a city. Analyses can be done at the firm's level,  $f$ , city  $c$ , industry  $i$ , and year  $t$ , as all data are available at this thin level.

Results are reported in table 4.6 with column 1 using the number of city commercial branches as a proxy for banking deregulation; column 2 uses the inverse of HHI, also named bank competition. For both columns, the access to credit at the provincial level (Long-term loan $_{pt-1}$ ) does not seem to play a role in the asset mix, as both coefficients are negative but not significant. The interaction between the two proxies for bank deregulation is negative and significant, which suggests that heightened competition across banks and an improvement of the screening process through the city commercial bank result in a reduction in the over-investment in tangible assets. The results support the mechanism proposed by Andersen (2017), in which constrained firms tend to invest relatively more in tangible assets. Relaxing the constraint gives the firm more flexibility in choosing the asset it wants to invest in, and they're more likely to invest in intangible assets. Reduced investment in tangible assets in profit to intangible improves the environmental performance of firms after increased competition in the banking industry (i.e., banking deregulation).

### **Scale effect**

The literature has documented that cheaper access to finance can lead to an increase in investment and production (Fazzari et al. 1988; Shapira and Zingales 2017). More resources are required without a change in the production process (i.e., lower input or production

**Table 4.6: Asset mix and and pollution emissions**

|  | Dependent variable: asset tangibility |                      |
|--|---------------------------------------|----------------------|
|  | (1)                                   | (2)                  |
| <i>Credit access</i>                                     |                                       |                      |
| Long-term loan <sub>pt-1</sub>                           | -0.072*<br>(0.036)                    | -0.083**<br>(0.038)  |
| Long-term loan <sub>pt-1</sub> × credit constraint       | -0.001<br>(0.020)                     | -0.007<br>(0.017)    |
| <i>Banking deregulation</i>                              |                                       |                      |
| No. of city branches <sub>ct-1</sub>                     | -0.0004<br>(0.0003)                   |                      |
| No. of city branches <sub>ct-1</sub> × credit constraint | -0.0001*<br>(0.000)                   |                      |
| Bank competition <sub>ct-1</sub>                         |                                       | -0.211<br>(0.170)    |
| Bank competition <sub>ct-1</sub> × credit constraint     |                                       | -0.080**<br>(0.031)  |
| <i>Control variables</i>                                 |                                       |                      |
| log(cashflow)  | -0.157***<br>(0.010)                  | -0.157***<br>(0.010) |
| log(current ratio)                                       | -0.035***<br>(0.006)                  | -0.035***<br>(0.006) |
| log(liabilities to asset)                                | -0.054***<br>(0.014)                  | -0.053***<br>(0.014) |
| log(output)  | 0.049***<br>(0.010)                   | 0.049***<br>(0.010)  |
| log(employment)  | 0.022**<br>(0.009)                    | 0.022**<br>(0.009)   |
| log(capital)   | -0.016***<br>(0.005)                  | -0.016***<br>(0.005) |
| log(age)   | 0.010*<br>(0.006)                     | 0.010*<br>(0.006)    |
| export to sale   | -0.008<br>(0.011)                     | -0.008<br>(0.011)    |
| credit constraint  | -0.062<br>(641.4)                     | -0.088<br>(640.7)    |
| log(gdp / pop)   | -0.049<br>(0.037)                     | -0.050<br>(0.037)    |
| log(gdp / pop) × credit constraint                       | -0.001<br>(0.005)                     | -0.0008<br>(0.006)   |
| log(FDI / gdp)   | -0.003<br>(0.005)                     | -0.003<br>(0.005)    |
| log(FDI / gdp) × credit constraint                       | 0.001<br>(0.003)                      | 0.001<br>(0.003)     |
| firm   | Yes                                   | Yes                  |
| year   | Yes                                   | Yes                  |
| industry   | Yes                                   | Yes                  |
| Observations   | 339,884                               | 339,884              |
| R <sup>2</sup>   | 0.885                                 | 0.885                |

This table reports estimates of equation 4.3.  $asset\ mix_{fcit}$  denotes the share of asset tangibility over total assets and is in log.  $Financial\ Dependencies_k$  which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan<sub>pt-1</sub> signifies the share of the total loan normalized by the province GDP; No. of city branches<sub>ct-1</sub> is the number of city commercial bank branches; Bank competition<sub>ct-1</sub> is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

efficiency). We test this channel in equation 4.4.

$$\begin{aligned} \text{Output}_{fckt} = & \alpha_0 \text{Credit access}_{pt-1} + \alpha_1 \text{Financial Dependencies}_k \times \text{Credit access}_{pt-1} + \\ & \alpha_2 \text{Bank deregulation}_{ct-1} + \alpha_3 \text{Financial Dependencies}_k \times \text{Bank deregulation}_{ct-1} + \\ & \beta_4 X_{fckt} + \beta_5 X_{ckt} + \mu_f + \gamma_t + \delta_c + \epsilon_{fckt} \end{aligned} \quad (4.4)$$

where the scale effect is proxy by the firm's level of *output*. We interact both financial development and banking deregulation (i.e. *Credit access*<sub>pt-1</sub> and *Bank deregulation*<sub>ct-1</sub>) with the *Financial Dependencies*<sub>k</sub>. We carefully control for macroeconomic change with GDP per capita and FDI over GDP, and a common set of variables at the firm level, namely  $X_{fct}$  includes usual controls found in the literature, namely *cash flow*<sub>fit</sub> and *current ratio*<sub>fit</sub>, *liabilities to assets*, *employment*, *capital*, *age*, and *export to sale*. The inclusion of industry and time ( $\gamma_i, \gamma_t$ ) fixed effects removes the trends associated with all firms in a particular industry. Finally, entering firms' fixed effects ( $\zeta_f$ ) removes all unobserved factors that contribute to a firm's output within a city. The results are nebulous because a credit market improvement can lead to higher/lower input or have no statistical link.

The results are available in table 4.7. In both columns, all coefficients of the variables of interest (*Credit access*<sub>pt-1</sub> and *Bank deregulation*<sub>ct-1</sub>) interacted with *Financial Dependencies*<sub>k</sub> are negative but not significant. This indicates that the change in the way banks are regulated does not play a role in the choice of the firm's level of output. Therefore, we can exclude the scale effect mechanism as a result of banking deregulation and ascertain that technology adoption indeed plays an important role in reducing emissions.

**Table 4.7: Scale effect and pollution emissions**

|  | Dependent variable: Output |          |
|--|----------------------------|----------|
|  | (1)                        | (2)      |
| <i>Credit access</i>                                     |                            |          |
| Long-term loan <sub>pt-1</sub>                           | -0.300*                    | -0.304*  |
|  | (0.175)                    | (0.162)  |
| Long-term loan <sub>pt-1</sub> × credit constraint       | -0.034                     | -0.023   |
|  | (0.052)                    | (0.021)  |
| <i>Banking deregulation</i>                              |                            |          |
| No. of city branches <sub>ct-1</sub>                     | -0.0005                    |          |
|  | (0.0005)                   |          |
| No. of city branches <sub>ct-1</sub> × credit constraint | 0.0001                     |          |
|  | (0.0001)                   |          |
| Bank competition <sub>ct-1</sub>                         |                            | -0.317   |
|  |                            | (0.363)  |
| Bank competition <sub>ct-1</sub> × credit constraint     |                            | -0.154   |
|  |                            | (0.106)  |
| <i>Control variables</i>                                 |                            |          |
| log(cashflow)  | 0.123***                   | 0.123*** |
|  | (0.006)                    | (0.006)  |
| log(current ratio)                                       | 0.002                      | 0.002    |
|  | (0.005)                    | (0.005)  |
| log(liabilities to asset)                                | 0.024                      | 0.024*   |
|  | (0.015)                    | (0.012)  |
| log(employment)  | 0.433***                   | 0.433*** |
|  | (0.020)                    | (0.016)  |
| log(capital)   | 0.104***                   | 0.104*** |
|  | (0.006)                    | (0.005)  |
| log(age)   | 0.061***                   | 0.061*** |
|  | (0.011)                    | (0.007)  |
| export to sale   | 0.075***                   | 0.075*** |
|  | (0.024)                    | (0.024)  |
| credit constraint  | 1.29                       | 1.28     |
|  | (822.8)                    | (808.9)  |
| log(gdp / pop)   | 0.026                      | 0.025    |
|  | (0.072)                    | (0.069)  |
| log(gdp / pop) × credit constraint                       | -0.005                     | 0.0010   |
|  | (0.027)                    | (0.011)  |
| log(FDI / gdp)   | 0.014                      | 0.014    |
|  | (0.008)                    | (0.009)  |
| log(FDI / gdp) × credit constraint                       | -0.002**                   | -0.003   |
|  | (0.001)                    | (0.005)  |
| firm   | Yes                        | Yes      |
| year   | Yes                        | Yes      |
| industry   | Yes                        | Yes      |
| Observations   | 339,884                    | 339,884  |
| R <sup>2</sup>   | 0.885                      | 0.885    |

This table reports estimates of equation 4.4. The dependent variable  $output_{fcit}$  is in log.  $Financial\ Dependencies_k$  which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan<sub>pt-1</sub> denotes the share of the total loan normalized by the province GDP; No. of city branches<sub>ct-1</sub> is the number of city commercial bank branches; Bank competition<sub>ct-1</sub> signifies the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%

## 4.8 Conclusion

This paper investigates the relationship between external borrowing and production-generated pollution emissions following a change in China's financial banking regulation from 1998 to 2007. More specifically, we capture the financial development by using the long-term bank loans by province (normalized by province GDP) along with the development of city commercial banks to demonstrate that the effect of the banking restructuring ameliorated the prevalent financial constraint on pollution emissions. Our results suggest that a better credit supply and the development of CCBs help private firms obtain cheaper credit and reduce pollution emissions disproportionately more in financially-dependent sectors. Easier and cheaper access to credit can prompt firms to make heavy investments in capital-intensive pollution control activities or foster investment in technology adoption. We exploit the richness of our dataset to investigate the channels through which credit conditions would have affected the emission of toxic discharge. The results show that more financially constrained sectors do not contribute to the pollution emission change from a purchase of pollution abatement equipment. However, cheaper and easier access to finance leads firms to invest in technology that can change the production process, thereby affecting both the productivity and energy consumption without purchasing pollution abatement equipment. Those investments are likely to reduce manufacturing costs and improve technical efficiency. The results indicate that firms reduce energy consumption through technology adoption in the aftermath of more intense bank competition in the most financially constrained industry. We then document the asset mix mechanism following Andersen (2017) model, where constrained firms invest relatively more in tangible assets because the bank requires collateral. This over-investment in asset tangibility has a positive correlation with pollution emissions. We demonstrate that firms have re-balanced their asset allocation when they have easier access to finance. Finally, we rule out the scale effect hypothesis, which stipulates financial development spurs investment and production without involving a change in the process. This result confirms that technology adoption has one of the main drivers of pollution re-



duction financed by better access to finance.

Banks play a salient role in developed and developing economies. They finance operating activities as well as investments. Banks are the primary funding source for corporations and SMEs in economies with an under-developed financial market. The literature has largely documented the role of financial liberalization in growth, productivity, and export, but evidence of the impact on the environment remains scarce. This paper fills the void by examining the effect and the mechanisms whereby banking deregulation might impact pollution emissions. Our findings highlight the positive effect of financial liberalization on the environment. This research demonstrates that policymakers from developing economies should not neglect competition in the banking sectors because it positively affects the environment. These findings bear even greater significance as the fight against climate change becomes increasingly essential.

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## 4.9 Appendix

**Table 4.8: Sewage charges and pollution emissions**

|  | Dependent variable: sewage charges |                     |
|--|------------------------------------|---------------------|
|  | (1)                                | (2)                 |
| <i>Credit access</i>                                     |                                    |                     |
| Long-term loan <sub>pt-1</sub>                           | 0.003<br>(0.170)                   | -0.006<br>(0.181)   |
| Long-term loan <sub>pt-1</sub> × credit constraint       | 0.374<br>(0.228)                   | 0.315<br>(0.211)    |
| <i>Banking deregulation</i>                              |                                    |                     |
| No. of city branches <sub>ct-1</sub>                     | 0.0010<br>(0.001)                  |                     |
| No. of city branches <sub>ct-1</sub> × credit constraint | -0.001**<br>(0.0004)               |                     |
| Bank competition <sub>ct-1</sub>                         |                                    | 0.159<br>(0.438)    |
| Bank competition <sub>ct-1</sub> × credit constraint     |                                    | -0.353*<br>(0.184)  |
| <i>Control variables</i>                                 |                                    |                     |
| log(cashflow)  | 0.013**<br>(0.006)                 | 0.013**<br>(0.006)  |
| log(current ratio)                                       | 0.0004<br>(0.006)                  | 0.0004<br>(0.006)   |
| log(liabilities to asset)                                | -0.010<br>(0.010)                  | -0.010<br>(0.010)   |
| log(employment)  | 0.036***<br>(0.011)                | 0.037***<br>(0.011) |
| log(capital)   | -0.0010<br>(0.006)                 | -0.0008<br>(0.006)  |
| log(age)   | 0.010<br>(0.007)                   | 0.010<br>(0.007)    |
| export to sale   | -0.015<br>(0.015)                  | -0.015<br>(0.015)   |
| credit constraint  | 0.248<br>(1,155.8)                 | 0.471<br>(1,184.3)  |
| log(gdp / pop)   | -0.018<br>(0.070)                  | -0.007<br>(0.068)   |
| log(gdp / pop) × credit constraint                       | -0.038<br>(0.034)                  | -0.043<br>(0.034)   |
| log(FDI / gdp)   | 0.010<br>(0.010)                   | 0.009<br>(0.010)    |
| log(FDI / gdp) × credit constraint                       | 0.022**<br>(0.009)                 | 0.019**<br>(0.009)  |
| firm   | Yes                                | Yes                 |
| year   | Yes                                | Yes s               |
| industry   | Yes                                | Yes                 |
| Observations   | 357,770                            | 357,770             |
| R <sup>2</sup>   | 0.529                              | 0.529               |

*sewage charge* refers to the charge paid by a firm and is in log. *Financial Dependencies<sub>k</sub>* which is computed as the share of capital expenditure not financed out of cash flow from operation; Long-term loan<sub>pt-1</sub> is the share of the total loan normalized by the province GDP; No. of city branches<sub>ct-1</sub> is the number of city commercial bank branches; Bank competition<sub>ct-1</sub> is the inverse of the Herfindahl-Hirschman Index (HHI). The score ranges from zero to one, with zero indicating the most regulation and one indicating the most deregulation. Heteroskedasticity-robust standard errors clustered at the city level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%



**Table 4.9: External finance dependence**

|   | CIC | Value |
|---|-----|-------|
| General Purpose Machinery   | 35  | -2.59 |
| Tobacco   | 16  | -1.54 |
| Measuring Instruments and Machinery for Cultural Activity and Office Work           | 41  | -1.34 |
| Textile Wearing Apparel, Footwear, and Caps   | 18  | -1.32 |
| Leather, Fur, Feather and Related Products  | 19  | -1.11 |
| Metal Products  | 34  | -0.93 |
| Printing, Reproduction of Recording Media   | 23  | -0.8  |
| Beverages   | 15  | -0.72 |
| Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products | 20  | -0.72 |
| Transport Equipment   | 37  | -0.72 |
| Furniture   | 21  | -0.65 |
| Artwork and Other Manufacturing   | 42  | -0.62 |
| Textile   | 17  | -0.48 |
| Processing of Food from Agricultural Products                                       | 13  | -0.47 |
| Plastics  | 30  | -0.47 |
| Medicines   | 27  | -0.44 |
| Electrical Machinery and Equipment  | 39  | -0.44 |
| Chemical Fibers   | 28  | -0.41 |
| Articles For Culture, Education and Sport Activity                                  | 24  | -0.4  |
| Foods   | 14  | -0.32 |
| Non-metallic Mineral Products   | 31  | -0.29 |
| Special Purpose Machinery   | 36  | -0.27 |
| Rubber  | 29  | -0.26 |
| Raw Chemical Materials and Chemical Products  | 26  | -0.23 |
| Smelting and Pressing of Non-ferrous Metals   | 33  | -0.1  |
| Communication Equipment, Computers and Other Electronic Equipment                   | 40  | 0.02  |
| Paper and Paper Products  | 22  | 0.07  |
| Smelting and Pressing of Ferrous Metals   | 32  | 0.33  |
| Processing of Petroleum, Coking, Processing of Nuclear Fuel                         | 25  | 0.62  |

Based on Chinese data is calculated at the 2-digit Chinese Industrial Classification (CIC) level. 29 Data available in the years 2004–2006 in the NBC Database. Computation used the aggregate rather than the median external finance dependence at the 2-digit industry level. One reason is the median firm in the ASIF database often has no capital expenditure.

## Chapter 5

# The role of industrial policy on product upgrading

## 5.1 Introduction

China's tax system has adopted a value-added export tax policy (VAT hereafter) to conduct significant structural reforms (Chandra and Long 2013). In practice, the Chinese export VAT refund mechanism disallows the complete recovery of the input VAT incurred for raw materials or components that are imported or purchased locally.<sup>1</sup> The value-added tax rebates affect thousands of products; in this context, the Chinese government sought to promote "high-value" products, such as aviation and medical commodities, and reduce the exportation of polluting activities. This paper analyzes the effect of manipulating the value-added export tax policy through the percentage of refunds entitled to product upgrading. Using the exogeneity of the VAT refund, We can isolate the variation in the product quality (HS6) within a city. The rebates frequently change over time for a full range of products in order to achieve the goals pursued by the government. Subsequently, we borrow the model of Fan et al. (2015) to explain the mechanism of quality adjustment. The industries facing tighter credit constraints impel firms to choose lower quality products. In response, a positive change in the VAT refund can offset the credit constraints by offering new liquidity to carry out investments.

The results show that following an increase in the VAT refund, targeted products are adjusted by upgrading the quality. The findings are in consonance with the prediction of the model of Fan et al. (2015), where tighter credit constraints force firms to produce lower quality products. We extend his model by providing a counter-balance force to credit constraints and adjusted quality. By increasing the refund granted to ordinary traders, firms use this excess cash flow to invest (in a fixed asset or innovative project), thereby

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<sup>1</sup>A value-added tax (VAT) is a consumption tax imposed on a product whenever a particular value is added at each stage of the supply chain, from production to the point of sale or export in the case of VAT exports. The amount of VAT that the buyer pays is predicated on the cost of the product, minus any costs of the materials used in the production that has already been taxed (source: <https://www.investopedia.com/terms/v/valueaddedtax.asp>). However, the VAT does not fully refund the VAT for exported goods in China.

improving the quality. Our results also reveal that ordinary traders ensure compliance with the importing countries' regulations. The use of non-trade barriers to raise the standard of the country of import compels ordinary traders to improve the quality.

We use the richness of the data to confirm that a positive change in the refund affects the product upgrading only when developed economies import the product. This finding is in line with the recent trade literature that proves theoretically and empirically that rich countries are willing to pay more for better quality, thus also boosting the exporter's margin. Next, we differentiate the products according to the Rauch (1999) classification. VAT refund only positively impacts products that have the capacity to demonstrate vertical and horizontal differentiation. Finally, we confirm that larger industries have more room for product upgrading than their smaller counterparts. Our model shows a differential of .16 percentage points in product upgrading following an increase in the refund for large industries compared to smaller ones. Firms in larger industries can use their new liquidity and financing capacity to source better-quality inputs or invest in R&D (Fan et al. 2015).

The VAT rebate policy is broadly embedded in the economic plan drawn by the Chinese government to circumvent the trap of low value-added exports and tackle environmental issues. The 10th Five-Year plan (hereafter referred to as FYP) was the first to introduce environmental goals formally. The next plan in 2006-2010 stressed the importance of improved energy consumption management. Both plans prioritized a shift in the export structure towards more value-added and high-technology products. In a recent paper, Gourdon et al. (2016) evaluate whether the Chinese government increased or removed the tax on energy-intensive or sophisticated high-technology products. We extend their analysis by demonstrating that the change in refund is ineffective for products exported in polluted sectors, which is in line with recent environmental policies. In addition, we provide evidence that the VAT refund is more beneficial for sophisticated products and industries engaging in R&D activities, whereas the product upgrading response is twice as large as the less sophisticated

products.

Our empirical strategy uses China's dual trade system to isolate the effect of the VAT refund on product upgrading. The customs data distinguishes the type of trade under which the product is exported. In China, exporting firms can primarily opt for one of two choices. On the one hand, "ordinary" trade is the most common for exporting firms. These firms are well integrated into the local economy and pay taxes on both import as well as export sides. Moreover, VAT applies to ordinary traders under the "exempt, credit, and refund" method. On the other hand, "processing" trade mostly imports raw materials, components, or intermediate input from abroad before assembling and re-exporting them. The Chinese government provides firms choosing this status with substantial benefits, namely duty-free imports and lower corporate taxes. The "no collection and no refund" method disqualifies processing traders from applying for refunds. Officials are of the view that the firms do not own capital or any other purchase form. We assert that the variation in the VAT refund only affects the aggregated flows of "ordinary" exports. In order to minimize the possible endogeneity between the status and the refund, our estimation strategy relies on a difference-in-differences approach to compare the product quality exported between the two trade regimes.

We use trade duality to isolate the variation in the tax refund at the HS6 product level, thus impacting the ordinary trade flow (treated group), to assess the change in the exported products' quality. The reliability of this strategy involves the characteristics of the control group being as similar as possible to the export flows from the ordinary trade regime. We keep the highest information detail of the data set by ensuring that under both types of trade, at least one product is exported to the same origin-destination combination in the same year. Our final data set comprises 192 cities, exporting 2742 HS6 products to 205 countries from 2003 to 2010.

We analyze the change in the quality by interacting the VAT refund at the product level with a dummy variable indicating the trade regime. More specifically, we construct the quality index using the Khandelwal methodology (Khandelwal et al. 2013). The advantages offered by this method are twofold. First, the index focuses on the vertical components of quality. The market share of a product for a given firm, conditional on the price, captures the quality. Unlike the unit price, the difference in production cost does not enter into the computation.<sup>2</sup> A larger market share is attributed to a higher quality. Secondly, the index is highly tractable; this means that we can estimate the quality of a given city–product–destination combination for both types of trade. The trade regime<sup>3</sup> is central to our strategy, and the quality reflects the change in the production mix within a city. Then we test the effect of the credit constraints on quality upgrading. We use four different measures to proxy for credit needs: external finance dependence, liquidity needs, asset tangibility, and R&D intensity. We interact separately with each measure with the VAT refund applied to an HS6 product and the regime. The model indicates that credit constraints negatively impact product quality. We assume that an increase in liquidity in a constrained industry would not only ameliorate the financial need but also promote investment. Our model results indicate that the VAT refund mitigates the credit constraint and explains the quality improvement mechanism.

Our identification strategy controls for fixed effects at different levels. We first use the control group to eliminate all the shocks affecting both trade types. We also include a city–product–regime fixed effect to control product composition differences. Then, we carefully account for the dissimilarity between the product over time and control the change in demand with the destination-year fixed effect. The dimensions of the data set ensure that we restrict the influence of cities’ sizes and any policy shocks to our baseline regressions.

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<sup>2</sup>Unit values are, at best, a noisy proxy for export quality being driven by other factors, including the production cost difference.

<sup>3</sup>Only ordinary traders can claim a VAT refund. Processing traders control for all inobservable effects on both types of firms.

This paper contributes to the literature on international trade and quality. Research has established that the characteristics of exporting/importing countries explain the variation in the price level (Crozet et al. 2011; Hallak and Sivadasan 2013; Kugler and Verhoogen 2011). On the supply side, bigger countries export more quantities and varieties than their smaller counterparts (Hummels and Klenow 2005; Schott 2004). Countries charge higher prices when the inputs come from developed countries (Hallak 2006; Manova and Zhang 2012). According to cross-country within-firm-level analyses, large firms charge a higher price, especially in distant markets, pay higher wages, and purchase inputs of higher quality to produce more expensive products (Bastos and Silva 2010; Görg et al. 2017). Our paper extends this literature. While most papers have concentrated on the characteristics of origin/destination countries, none have considered the role played by industrial policy. One notable exception is the paper by Bas and Strauss-Kahn (2015) which found that trade liberalization in China enabled firms to source more expensive goods from developed countries and exported them at a higher price. However, they examined the negative role played by import tax. In this paper, we focus on VAT refunds. It is also noteworthy that VAT refund has easily been manipulated on a significant scale both upwards and downwards (Gourdon et al. 2022). Our paper introduces a new and unexplored variable in the trade literature. That is, we use the stock of non-trade barriers to explain the change in the quality. Chinese exporters comply with the change in regulation in the import market.

This paper is organized as follows: the first section presents the trading system in China. The second section presents the Chinese VAT system. The third section defines and elucidates the VAT rebate system, while the fourth section outlines the theoretical motivation. The fifth section expounds on the empirical strategy, the data, and the variables' construction. The sixth section reports the main results concerning the impact of VAT refunds on quality upgrading and the heterogeneity effect. Then, we explain the underlying mechanism in the seventh section. The last section concludes the paper.

## 5.2 Trade system in China

The trading system in China is both large and complex. There are as many as 18 types of categories in which trading firms can operate. For our analysis, we narrow our focus to the two central regimes, which alone comprise more than 95 percent of commercial transactions. Therefore, the trading system can be summed up as a system including ordinary trade and processing trade. Firms registered with an ordinary trade license can freely import goods and sell their products either in the domestic market or overseas. However, this freedom is not reciprocal for firms holding a processing license. The processing activity is primarily assembling, and firms must export the entire processed output. Within processing trade, there are two categories: *Processing trade with supplied materials* and *processing trade with imported materials*. *Processing trade with supplied materials* is the most constraining one because firms do not own inputs or capital, which remain the property of the foreign party. Firms that export under the *processing trade with supplied materials* are exempt from paying both import and export taxes. From a legal standpoint, the firm does not possess the goods; this exempts it from paying import/export taxes. This special treatment has been in place for over 30 years (Bas and Strauss-Kahn 2015). Exporting firms merely assemble and export the finished product to the country from which the intermediate goods originated. Alternatively, firms that process with imported materials have more flexibility in the origin of intermediate goods but are not exempt from tax. We exclude the latter from our analysis to fully compare ordinary trade (affected by the tax) and processing trade (not affected by the tax).



## 5.3 The VAT rebate system

### 5.3.1 Definition of VAT export system

In China, all exported goods are subject to VAT, with the base rate being 17 percent.<sup>4</sup> The Chinese system is different from developed countries in terms of the way in which it refunds. VAT rebate for exported goods refers to a system of refunding the VAT already paid/payable to the exporter or granting exemption to the exporter. The conditions for collecting the VAT refund are complicated, and only firms in ordinary trade or processing trade with purchased materials are entitled to receive a VAT refund. Circular No. 7 (Finance Ministry and the State Administration of Taxation in China 2002) dating from 2002 specifies the method for calculating VAT.

The formula includes two terms, namely the payable part of VAT and the non-exempt and non-creditable part of VAT (i.e., VAT exemption), computed as follows:

$$\text{Vat payable} = \sum_k (\text{domestic sale}) - \left( \sum_{k'} \text{inputs}_{k'} - \text{VAT exemption} \right) \quad (5.1)$$

$$\text{VAT exemption} = \sum_k \left( \text{Export sale} - \sum_{k'} BIM_{k'} \right) * (\text{VAT rate}_k - \text{VAT rebate}_k) \quad (5.2)$$

where  $k$  denotes the product and  $k'$  defines the intermediate inputs required to produce  $k$ .

The first term (5.1) does not differ from the general VAT calculation. The second term

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<sup>4</sup>A reduced rate of 13 percent is applied to food grains, tap water, heating, cooling, coal, gas, books, magazines, feed, chemical fertilizers, and other goods the State Council prescribes.

(5.2) corresponds to the tax. Notably, all intermediate goods are subject to VAT except those from the "bonded area". Generally, no customs duties and import taxes would be levied on bonded imports.<sup>5</sup>

Products subject to a discount rate close to the VAT rate will allow companies to pay less tax. The company can claim a VAT refund for the extra money paid if the VAT payable is negative. Within the formula, it is striking that the VAT rate is not proportional to the value added. It solely relied on the quantity exported. As a case in point, a product with a 17 percent VAT rate and a 13 percent discount rate means 4 percent tax for the exporting company (i.e., a 76% refund from the tax paid calculated by dividing the rebate rate by the base rate). The amount of VAT payable is based on the quantity exported.

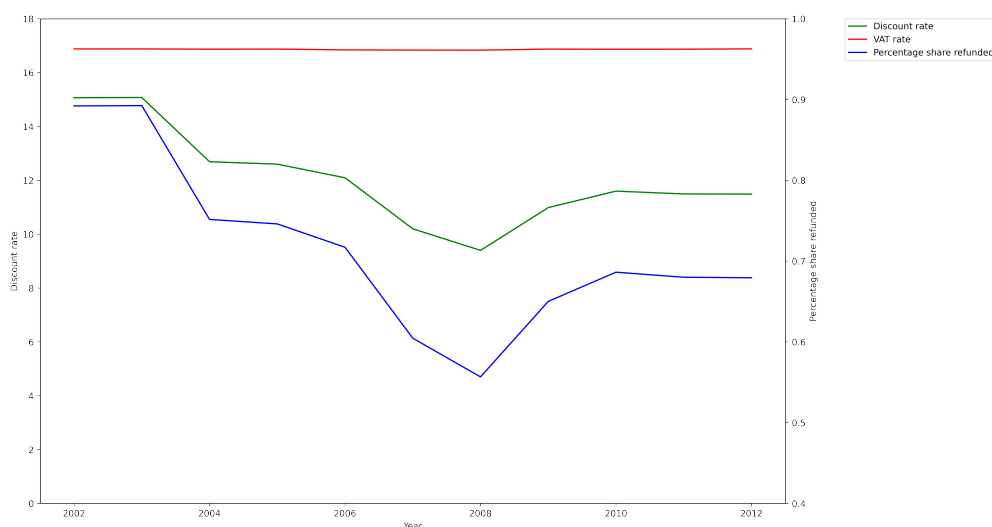
The VAT system of China excludes firms exporting under the processing exports with supplied materials category (as explained in section 5.2). According to the Chinese authorities, both the equipment and the intermediate goods remain the property of the foreign party. The sole objective of exported products with supplied materials is to assemble a good on behalf of a foreign third-party company. This system makes the VAT refund ineligible even if the company has bought inputs.

The country's VAT system has undergone many changes since 1994. Initially, the system served as a means of improving the competitiveness of Chinese firms. Since then, the government has continued using the VAT tax system to promote targeted industrial sectors. VAT rebates impact all products in a heterogeneous manner. During the 2003-2007 period, the trend moved somewhat downwards, but some products were affected much more than other products (see figure 5.1. The VAT refund bounced back to react to the international economic condition during the financial crisis of 2008.

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<sup>5</sup>Imported goods with bonded status can be developed, processed, stored, and imported into China after paying duties or shipped out of China without paying duties.

**Figure 5.1: VAT rebate and VAT refund across time**



**Note:** VAT rate is the base rate, VAT rebate is the amount an exporter eligible for a refund can claim, whereas the percentage share refunded is the percentage of the tax refunded. It is equal to the VAT rebate divided by the VAT base rate. **Source:** Author's own computation. The data on the VAT rates in China comes from the *ETAX Yearbooks of Chinese Customs*

## 5.4 Theoretical motivation

Our analysis evaluates how firms adjust quality following a change in the VAT rebate. The VAT rebate is exogenous from the standpoint of firms and is often a result of a trade policy such as the promotion of export embedded with higher added-value and high technology products or a reduction in the export of polluting activities (Gourdon et al. 2016). Promotion of product upgrading requires substantial effort for a firm. Typically, investment in R&D is a prerequisite or subsequent cash flow to purchase better input (i.e., to purchase high-quality inputs to quality-upgrade exports). In the export market, companies are known to face different degrees of financial needs, which, as shown by Fan et al. (2015), directly impact quality choices. Previous research has demonstrated that exporters have higher credit needs than domestic producers (Amiti and Weinstein 2011; Feenstra et al. 2014), or credit constraints prevent exports to numerous destinations, reducing global sales and sales within each destination-product market (Berman and Héricourt 2010; Greenaway et al. 2007; Minetti and Zhu 2011; Muûls 2015). More generally, credit constraints impede a firm's

investment in technology upgrades or significantly reduce productivity (Bustos 2011; Levine and Warusawitharana 2021). Credit constraint is detrimental for exporters because the fixed cost involved in exports is larger than serving the domestic market (Melitz 2003) and larger upfront costs are necessary, which cannot be financed from profit or cash flow. Fan et al. (2015) developed a theoretical model to explain why credit constraints affect the choice of quality. In the model, quality is a function of productivity and financial constraint. It is due to the upfront cost that firms with tighter credit constraints choose a lower product quality. This prediction echoes Phillips and Sertsios (2013) where product quality decreases when companies are in financial distress given that it reduces the firm's incentive to invest in quality.

Our analysis is based on the model of Fan et al. (2015) where quality decreases with credit constraint. We extend his model by stating the VAT tax rebate can ameliorate the credit needs faced by constraint firms to finance either the larger upfront cost required in the export market or by investing in innovation. Put differently, the change in VAT rebate will promote investment in fixed capital, R&D, and innovation by relieving firms of a tax burden. Hence, this new cash inflow is used to increase the amount of capital equipment put into production and increase R&D expenses, thus paving the way for product upgrading.

## **5.5 Empirical strategy, data, and variables construction**

### **5.5.1 Empirical strategy**

China has experienced a drastic change since joining the WTO in 2001. The accession lifted many barriers, and tariffs declined, except for VAT export-related tax. The VAT export tax continues to vary considerably across industries. China also has an unprecedented trading system, whereby it differentiates between ordinary and processing trade. "Processing" ac-

tivities offer many advantages, the most important of which is not having to pay taxes on imports/exports. To measure the effectiveness of the policy on the ordinary trade's product upgrading (treatment group), we use the ineligibility of the processing trade to a tax refund as a control group. In addition, we utilize the availability of the VAT rebate to construct the share of a refund at the HS6 level throughout the period between 2003 and 2010. We calculate the VAT refund as the value of the VAT rebate rate divided by the actual tax rate. To summarize, the VAT refund rate goes from 0 to 1, where 1 represents a full refund.

Our main regression is as follows:

$$\begin{aligned}
\text{Quality}_{c,k,j,t}^R &= \alpha \text{VAT Refund}_{k,t-1} \times \text{Eligibility}^R + \\
&\quad \beta \text{Import tax}_{k,t-1} \times \text{Eligibility}^R + \\
&\quad \beta \text{NTM}_{k,j,t-1} \times \text{Eligibility}^R + \\
&\quad \theta X_{c,s,t-1}^R + FE_{c,k}^R + FE_{k,t} + FE_{j,t} + \epsilon_{c,k,j,t}^R
\end{aligned} \tag{5.3}$$

The dependent variable is a quality indicator,  $\text{Quality}_{c,k,j,t}^R$ , calculated at the HS6 product level  $k$ , exported by city  $c$  under the trade regime ordinary or processing  $R$  to country  $j$  at year  $t$ . We isolate the effect of the VAT refund by interacting with a dummy variable that captures the trade status,  $\text{Eligibility}^R$  which takes the value of one if the flow is eligible for a refund and zero otherwise. The refund should only affect the product upgrading belonging to the ordinary trade regime, and leave the processing regime impervious to the variations in the refund. The control group represented by the second regime type plays an essential role in our estimation. It allows us to control all the unobservable variables and affect the quality differently. We lag all the right-hand-side variables by one year. We then add an interaction between import taxes,  $\text{Import tax}_{k,t-1}$ , and the trade regime,  $\text{Eligibility}^R$ , to control the effect of trade openness on quality (Bas and Strauss-Kahn 2015). We add another interaction term between the number of non-trade measures (TBT/SPS) ( $\text{NTM}_{k,j,t-1}$ ) being used in the importing country (i.e., the destination country) for each product with the trade regime.

Finally, we control the export share by export trade flow’s ownership (domestic vs. foreign and private vs. SOE) under both regimes. Our specification includes several fixed effects to mitigate potential problems from confounding factors. First, we add a city-product-regime fixed effect,  $FE_{c,k}^R$  to capture all the time-invariant factors affecting products exported by city  $c$  across the regime. Next, we control for the product year dummy,  $FE_{k,t}$ , thereby providing an additional level of control, and encompassing all the shocks and developments in the economies to which China exports. Our last fixed effect control is for any time difference between the destination country, such as a difference in demand of product  $k$  with  $FE_{j,t}$ . The standard error is clustered at the product level, and the term  $\epsilon_{c,k,j,t}^R$  refers to the error.

## 5.5.2 Construction of data and variables

### VAT refund

Our analysis concentrates on the effect of the VAT refund on the quality of products exported under the eligible trade regime. The data on the VAT rates in China comes from the *ETAX Yearbooks of Chinese Customs*. This document provides all the VAT rates applied annually to HS8 products. Unlike rebates, VAT rates barely vary during the period. We must aggregate the information at HS6 instead of HS8 using the average of the VAT rates and rebates to be consistent with the international classification of HS products. Finally, the data represents 2742 HS6 products from 2003–2010.

Table 5.1 illustrates the rebate distribution over the years. For instance, 43 different refunds were applied in 2003 in comparison to 117 refunds in 2010, the latest year of our analysis. We note that the percentage of refunds decreases over time, from an average of 90% in 2003 to 70% in 2010, with the lowest refunds being at 60% in 2009.

In Figure 5.2, we plot the average export rebate of 84 HS2 industries in 2003. Each HS2 may contain between 6 and 513 products. Overall, there is substantial heterogeneity across

**Table 5.1: Distribution of unique VAT refund share at the HS6 product level**

| year | count | unique refund | mean | std  | min  | 25%  | 50%  | 75%  | max |
|------|-------|---------------|------|------|------|------|------|------|-----|
| 2003 | 2713  | 43            | 0.90 | 0.10 | 0.38 | 0.76 | 0.88 | 1.00 | 1   |
| 2004 | 2731  | 45            | 0.90 | 0.10 | 0.38 | 0.76 | 0.88 | 1.00 | 1   |
| 2005 | 2739  | 44            | 0.76 | 0.14 | 0.00 | 0.76 | 0.76 | 0.76 | 1   |
| 2006 | 2735  | 45            | 0.75 | 0.15 | 0.00 | 0.76 | 0.76 | 0.76 | 1   |
| 2007 | 2587  | 62            | 0.72 | 0.17 | 0.00 | 0.71 | 0.76 | 0.76 | 1   |
| 2008 | 2586  | 109           | 0.63 | 0.22 | 0.00 | 0.53 | 0.65 | 0.76 | 1   |
| 2009 | 2588  | 100           | 0.60 | 0.28 | 0.00 | 0.33 | 0.75 | 0.79 | 1   |
| 2010 | 2586  | 117           | 0.70 | 0.29 | 0.00 | 0.53 | 0.85 | 0.88 | 1   |

**Note:** The table briefly describes the statistics about the VAT refund distribution. The VAT refund is computed by dividing the VAT rebate rate over the VAT rate. Values close to one imply a larger tax refund. The column *count* indicates the number of products affected by the VAT rebate in our sample. The second column, *unique refund* shows the number of unique values of VAT refunds per year. As a case in point, there are 49 different values of the VAT refund in 2003, stretching from 0 to 1.

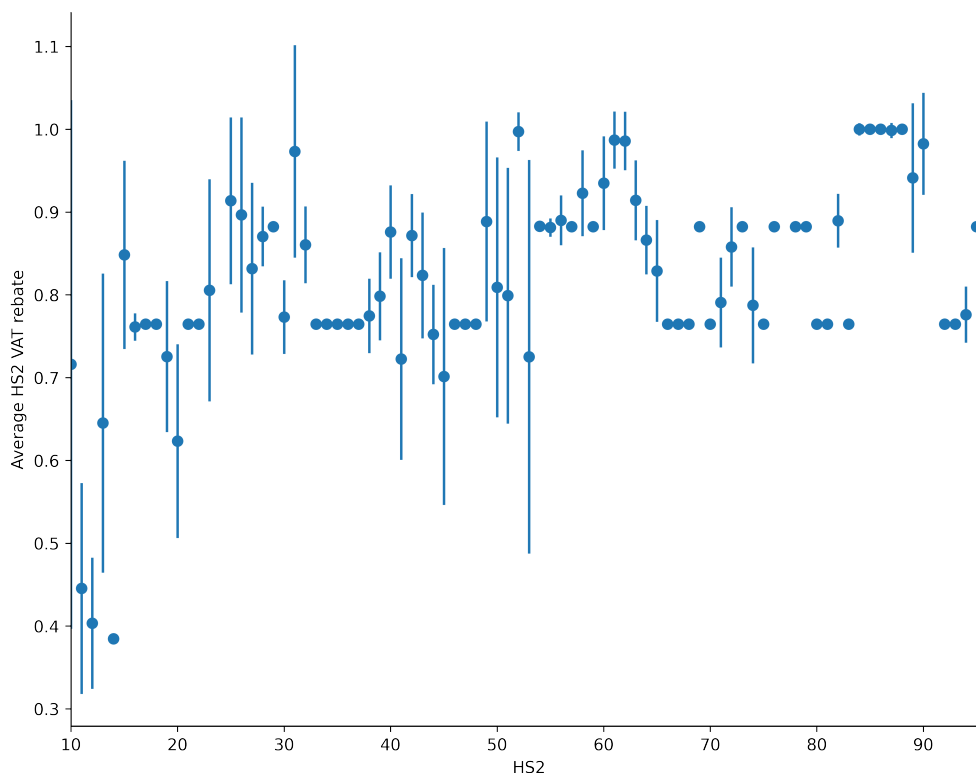
sectors, with relatively high rates for industries 30 and 70. Moreover, some industries have a great deal of variation. For example, industry 10 encompasses 66 percent of the tax with a standard deviation of 0.45.

### Regime: processing trade *versus* ordinary trade

Trade data is collected on a monthly basis by the Chinese Customs and made public in the *Chinese Customs–Trade Statistics* book. For our analysis, we restrict our focus to the domestic companies exporting manufactured products from 2003–2010, thus excluding agricultural sectors<sup>6</sup> and flows originated by a foreign company. The data reports the price of HS8 products in dollars along with the quantity exported to a country. Information on the location and firms’ trade licenses is also available. We aggregate all trade flows at the city-product-destination level over time, and use the trade status of the export flow to differ-

<sup>6</sup>We drop the HS6 products with a classification code above 980.000, corresponding to services and wholesale, as well as those lower than 100.630, for animal products and vegetables.

**Figure 5.2: Average VAT rebate share and standard error within each HS2 (2003)**



**Note:** Average VAT rebate share and standard error within each HS2 (2003) **Source:** Author's own computation. The data on the VAT rates in China comes from the *ETAX Yearbooks of Chinese Customs*

entiate processing from ordinary.<sup>7</sup> Eventually, we have 192 cities, exporting 2742 products to 205 countries. We also ensure that for any given city-destination-year, a product is exported under both regimes.

### Quality measure

Early literature (Verhoogen (2008); Crozet et al. (2011); Kugler and Verhoogen (2011); Hallak and Sivadasan (2013)) assumes that quality can be inferred through unit price (i.e., higher price leads to higher quality). However, it appears that unit prices capture both horizontal differentiation as well as other factors such as production costs (Khandelwal 2010). To overcome this issue of unit price not picking quality only, we construct our explanatory

<sup>7</sup>Notably, we focus on the ordinary trade regime and processing with assembly.



variable by following the model of *adjusted quality prices* (Khandelwal et al. 2013), in which the demand is given by  $x_{c,k,j,t} = q_{c,k,j,t}^\eta p_{c,k,j,t}^{-\sigma} P_{jt}^{\sigma-1} Y_{jt}$ . The equation is the demand  $x$  from city  $c$ 's exports of product  $k$  in importing country  $j$  at time  $t$ ,  $Y_{jt}$  denotes the total income of country  $j$  and  $p$  represents the price level, while  $q$  is the effective quality (quality as it enters in the consumer's utility). In this model, the quality is indirectly inferred from the log of the aforementioned equation. A major advantage of using the *adjusted quality prices* model is its inherent flexibility. We are interested in determining the effect of a change in the VAT refund on product upgrading within ordinary trade. For this reason, we can adjust the empirical equation by estimating the actual quality as follows:

$$\ln(x_{c,k,j,t}^R) + \sigma \ln(p_{c,k,j,t}^R) = \varphi_k + \varphi_{jt} + \epsilon_{c,k,j,t} \quad (5.4)$$

where  $x_{c,k,j,t}^R$  denotes the demand of country  $j$  for a product exported  $k$  by city  $c$  at time  $t$  under the trade regime  $R$ . Using the log of the demand function, the quality of each city-product-country-year-regime is merely the residual of an OLS regression using an empirical value for sigma (i.e., the elasticity of substitution).

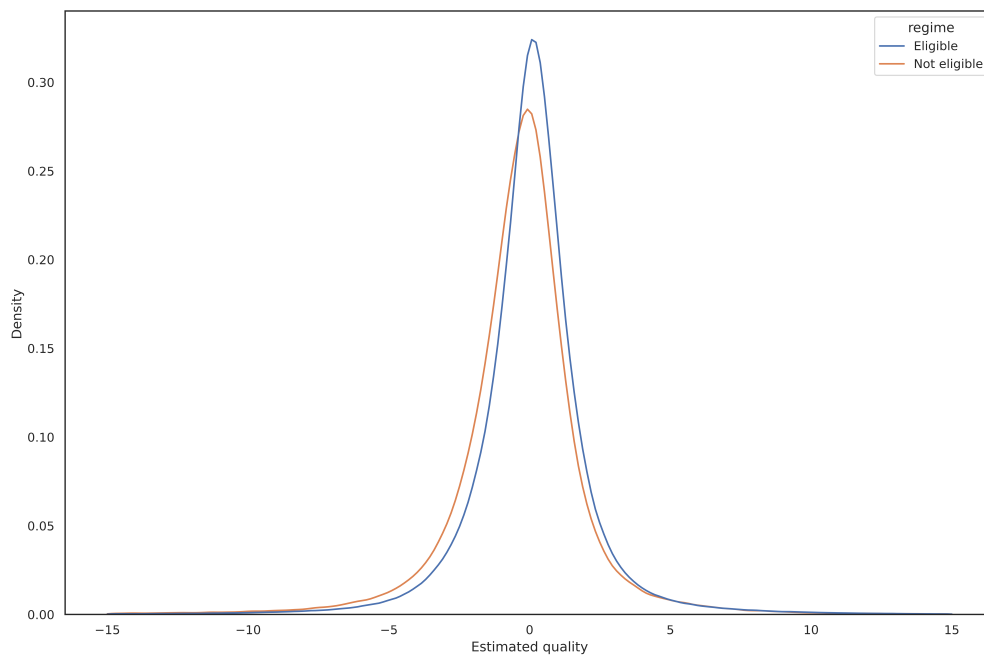
The fixed effect  $\varphi_{jt}$  controls the price index  $P_{jt}$  and the total revenue  $Y_{jt}$ , while the fixed effect  $\varphi_k$  takes variations between products into consideration. The elasticity of substitution is borrowed from Broda and Weinstein (2006), who estimated the  $\sigma$  for over 90 HS3 sectors in China. The quality is determined by  $\ln(\hat{x}_{c,k,j,t}^R) = \hat{\epsilon}_{c,k,j,t}/(\sigma - 1)$ , where the residual by the elasticity of substitution minus 1.<sup>8</sup> We use the log  $x_{c,k,j,t}^R$  and  $p_{c,k,j,t}^R$  from the customs database to estimate the quality. This approach is rather simple and intuitive: "conditional on price, a variety with a higher quantity is assigned higher quality". To examine the effect of the VAT refund on quality improvement, we use the quality measure as the dependent variable. In the end, we have the adjusted quality for both trade flows exported by a city to

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<sup>8</sup>We infer quality from the demand side and do not specify a model that accounts for firm quality choice. According to our assumption, quality is an attribute that raises consumer demand other than price.

a destination country for each year available. In order to provide a first illustration of the difference in adjusted quality between the two different regimes (ordinary *versus* processing), we present the distribution of quality in figure 5.3. The blue line represents the trade status eligible for a refund, whereas the orange line signifies the trade status that is not eligible. The graph indicates a distribution shift to the right for the eligible trade system compared with the ineligible trading system. We explore the VAT refund mechanism change to explain the difference in quality among traders.

**Figure 5.3: Estimated quality between ordinary traders and processing trader**



**Note:** VAT rate is the base rate, VAT rebate is the amount an exporter eligible for a refund can claim, while the percentage share refunded is the percentage of the tax refunded. It is equal to the VAT rebate divided by the VAT base rate. **Source:** Author's own computation. The data on the VAT rates in China comes from the *ETAX Yearbooks of Chinese Customs*

As robustness checks, we also follow the recommendation of Anderson and van Wincoop (2004) to construct quality measures by setting the elasticity as 5 and 10. Moreover, we also validate our results using a low value of sigma, as suggested by the IO literature. Consequently, we measure the quality using the elasticity of substitution equal to 3.

Our dataset is rich in several dimensions. First of all, our dataset stretches from 2003 to

2010, whereas most of the previous studies have covered the 2000-2006 period. Secondly, we can compute the quality for each city-product-destination for both regimes (ordinary *versus* processing). In our analysis, we distinguish the type of destination country and the type of products. Table 5.2 provides preliminary insights from our dataset. The average estimated quality is equal to .057, with a large difference between developed and developing economies (.062 for the former and -.028 for the latter). An analysis of the quality between eligible and non-eligible for a rebate shows a positive absolute difference for ordinary traders either when we differentiate the type of country or the type of product.

**Table 5.2: Summary statistic about product quality and VAT refund share**

|                               |              | Product quality | VAT refund share | Nb products/countries | nb of obs |
|-------------------------------|--------------|-----------------|------------------|-----------------------|-----------|
| <i>Full sample</i>            |              |                 |                  |                       |           |
| Full                          | All          | 0.057           | 0.73             | 2742/205              | 615085    |
| <i>Country classification</i> |              |                 |                  | <i>Nb countries</i>   |           |
| DC                            | all          | 0.062           | 0.731            | 144                   | 580457    |
|                               | Not eligible | -0.108          | -                | -                     | -         |
|                               | Eligible     | 0.231           | -                | -                     | -         |
| LDC                           | all          | -0.028          | 0.717            | 61                    | 34628     |
|                               | Not eligible | -0.170          | -                | -                     | -         |
|                               | Eligible     | 0.120           | -                | -                     | -         |
| <i>Product classification</i> |              |                 |                  | <i>Nb products</i>    |           |
| Heterogenous                  | All          | 0.056           | 0.733            | 2549                  | 589578    |
|                               | Not eligible | -0.119          | -                | -                     | -         |
|                               | Eligible     | 0.231           | -                | -                     | -         |
| Homogeneous                   | All          | 0.079           | 0.661            | 193                   | 25507     |
|                               | Not eligible | 0.059           | -                | -                     | -         |
|                               | Eligible     | 0.100           | -                | -                     | -         |

Product quality measures the quality following the methodology of Khandelwal et al. (2013). The VAT refund share is the percentage share refunded, and is equal to the VAT rebate divided by the VAT base rate. A VAT refund share equal to 1 indicates a full refund. The group Eligible corresponds to the ordinary traders eligible for a VAT refund, and the group Not eligible corresponds to the processing traders who are not eligible for a refund. The first row shows the summary statistics. LDC and DC are defined according to the World Bank's country classification. Homogeneous and heterogeneous goods are defined according to the official list of goods' classification from Rauch (Rauch 1999).

## External credit demand/credit constraint

Firms must finance a fraction of the costs (fixed and variable) to meet the production level. We follow Manova et al. (2015) to capture an industry's financial needs using four different measures. The idea underpinning these measures is that if an industry is more financially vulnerable, it is also more likely to face binding credit constraints. As pointed out by Manova et al. (2015), these measures are exogenous to the firms and reflect the characteristics of the industry. In this regard, we use the industry's *external finance* dependency, defined as the industry's exposure to the banks. The computation of the industry's external finance dependency is a straightforward process; it is the share of capital expenditure not financed with cash flow from operations. Previous works have used US data to proxy for exposure to external finance (Rajan and Zingales 1998; Claessens and Laeven 2003; Kroszner et al. 2007) and in the context of China (Jarreau and Poncet 2014; Manova et al. 2015; Fan et al. 2015). Secondly, we use *Asset tangibility* to proxy the credit constraint. *Asset tangibility* is defined as the share of the net value of fixed assets in the total value of book assets. Banks only make grants for investments in tangible assets serving as collateral. Hence, a larger value of *Asset tangibility* implies fewer credit constraints. Then, we use *RD intensity* calculated as the R&D spending divided by the ratio of the total sales. Large values of *RD intensity* indicate more credit constraints because industries engaged in research and development are often capital intensive, hence necessitating large financial resources. Finally, we use the *liquidity needs* developed by Raddatz (2006) computed as the ratio of inventories over annual sales. It measures the ability of a company to pay short-term obligations or those due within one year. We borrow the values of credit constraint (*external finance*, *Asset tangibility*, *RD intensity* and *liquidity needs*) from Kroszner et al. (2007). These indicators use data on all publicly traded U.S.-based companies from Compustat's annual industrial files. Each measurement is averaged over the 1980–1999 period for the median US firm in each 3-digit ISIC sector. We then map each 3-digit ISIC sector to our HS6 products. <sup>9</sup>

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<sup>9</sup>An R package provides a list of concordance <https://github.com/cran/concordance>

These measures have also been employed in the context of China (Fan et al. 2015; Manova et al. 2015; Jarreau and Poncet 2014). We follow the previous literature by assuming that the technological component is comparable between both countries. Manova et al. (2015) also indicate that the ranking of industries with respect to their financial vulnerability remains relatively stable across countries.

### **Non-tariff measure**

Recent studies have pointed to the role of non-tariff measures on the quality of imported products through tighter regulation. According to the Multi-Agency Support Team (MAST) classification, non-tariff measures (NTM) are "policies measures, other than ordinary customs tariffs, that can potentially have an economic effect on international trade in goods, changing quantities traded, or prices or both". This classification follows international regulations mandated by the WTO along with other organizations. NTM is traditionally perceived as negative for trade in the same spirit as the tariff. The impediment to trade is brought up as the underlying reason. This view often translates to a lack of research and understanding on the part of policy circles on the role of NTM in international trade. This current research attempts to alleviate this misconception about NTM and provide some understanding of the impact of these different measures on the quality of exported products. Our paper focuses on two specific categories of NTM among the ten categories: *Sanitary and Phytosanitary Measures* and *Technical barriers to trade*.<sup>10</sup> The TBT and SPS aim to achieve better regulation and higher standards to tackle market imperfections. The measures included in the TBT and SPS provide the countries with the authority to impose restrictions on low-quality products which the regulator perceives as harmful to the consumer, the plant life, the environment, etc. Unlike quotas, for instance, which clearly reduce the quantity imported and raise the price for the consumer, TBT and SPS can serve myriad purposes

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<sup>10</sup>The ten categories are 1) ADP - Antidumping, 2) CVD - Countervailing duties, 3) EXS - Export subsidies, 4) QRS - Quantitative Restrictions, 5) SFG - Safeguards, 6) SPS - Sanitary and Phytosanitary Measures, 7) SSG - Special Safeguards (agriculture), 8) STE - State trading enterprises, 9) TBT - Technical barriers to trade, 10) TRQ - tariff-rate quotas.

and are generally acceptable to the consumer. If a product deteriorates its health, the regulator can safeguard the market by imposing higher standards, thus impelling the importer to purchase higher quality products.

The research on NTM is scarce due to the difficulties of collecting and maintaining a dataset with all the regulations other than tariffs in place. In the present paper, we use the dataset maintained by the WTO<sup>11</sup> and enriched by the dataset from the Temporary Trade Barrier Database<sup>12</sup> (Limão 2012). The dataset has been supplemented by Ghodsi et al. (2017) to account for missing HS codes.<sup>13</sup> The dataset contains information from more than 100 countries, importing over 5.000 HS6 products from 1995 to 2019. The data indicates that the number of NTM increases substantially over time, as shown in figure 5.4. The blue line corresponds to the TBT measures and the green line to the SPS. A positive trend can be observed. Notably, the developed economies have adopted much more NTM than the rest of the world. In 2010, the United States promulgated 972 new TBT and SPS combined, followed by 600 for South Korea and 582 for the European Union (EU). These figures are much larger than the ones observed in developing economies.

We use this product-countries information to compute the stock of measures in place by year. We assume that when an importing country raises the standards, Chinese exporters are forced to comply by improving the quality.

## Control variables

We extend our model with the inclusion of three control variables. Firstly, we include the import tax rate interacting with the trade regime since tax aims to affect only ordinary trade. Collecting the data from the Chinese MFN tariffs at the HS6 from the WITS (World Bank) database, we select the most favorite nation-applied tariffs set by China for the rest of the world. We compute the simple average of MFN tariffs as a measure of nominal protection

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<sup>11</sup>accessible in this URL <http://i-tip.wto.org/goods/default.aspx?language=en>.

<sup>12</sup><https://www.chadpdown.com/temporary-trade-barriers-database/>.

<sup>13</sup>The dataset is available here: <https://wiiw.ac.at/wiiw-ntm-data-ds-2.html>.

**Figure 5.4: Number of newly applicable NTM (TBT and SPS over time**



**Note:** TBT and SPS aim to achieve better regulations and higher standards. **Source:** Author's own computation. The data on the NTM comes from the WTO, TTBD and is harmonized by Ghodsi et al. 2017

applied to imports into China. Next, we construct the city-product export share of foreign *versus* domestic, and private *versus* SOE for each regime. This information is generated from the trade data conducted by China's customs for the 2003–2010 period.

We have a dataset with 192 cities, exporting 2733 products to 205 countries from 2003–2010. Our dataset comprises 28% of products available for less than three years (10% available for one year only and 9% for two or three years). Importantly, 20% of the products (550) are available for a period of four years, and 30% of the products are available each year. Also, 41% of the countries import products from China from 2003 to 2010, and less than seven percent for one year only. The dataset also ensures that both trade regime exports each city-product-destination for each year.

## 5.6 Results

### 5.6.1 Baseline regression

Recent works on the export data for firms show the enormous gains derived from product upgrading. The production of higher-quality goods is attributable to the purchase of more expensive, intermediate inputs often originating from developed countries (Bas and Strauss-Kahn 2015), a depreciation of the currency (Hu et al. 2021), or an improvement of productivity; investment in new technology, and better know-how (Hausmann2007-ys, Hausmann2007-wa).

We investigate the impact of a change in the VAT export rebate on product upgrading for a panel of Chinese cities from 2003 to 2010. Our econometric strategy uses the duality of the Chinese trading system to implement a difference-in-difference estimation. The dependent variable is an indicator of quality measured for the city–product–year–destination for both trading systems. The total export flows coming from processing traders constitute the control group given that they cannot be eligible for a VAT refund owing to the nature of the transactions they conduct with their foreign partners.

Table 5.3 reports the results that regress the quality exported to the VAT refund for a city, HS6 products, destination, and year. We begin by estimating the effect of a change in the VAT refund on quality for each (of the two) regime separately. Column 1 reports the results for the processing trade regime (non-eligible for a refund), and column 2 reports the coefficients for the ordinary traders. If our strategy holds, we should expect positive and significant results for the trading system eligible for a refund and not significant for the other. Due to the nature of our strategy, the number of observations between columns 1 and 2 is identical. We only keep transactions carried out from both regimes at each city-product-destination-year to ensure that we can compare the difference in quality. We



include a product and city fixed effect. The preliminary results indicate that quality improves following a positive change in the VAT refund only for the eligible trade system. In columns 3 to 10, we estimate equation 5.3. Each column controls three types of fixed effects: city-product-regime, product-year, as well as destination-year. In column 1, we interact the trade regime dummy with the VAT refund. The sign and significance of the coefficients show that the VAT refund has a positive effect on the quality of the goods exported by ordinary trade compared with processing. An increase in VAT refund positively impacts product upgrading of domestic ordinary exports. Meanwhile, the import tax and regime coefficients are negative and significant, which is aligned with the recent findings from Bas and Strauss-Kahn (2015). An increase in the import tax is detrimental to product upgrading. In our estimation, accounting for the non-trade barriers imposed by the importing countries (i.e., destination) is another key interaction term that explains the change in quality. The coefficient of the stocks of NTM (TBT and SPS) is negative and significant while interacting with the regime; meanwhile, the coefficient is positive and significant at 5%. When the importing market adds higher standards to the import market, Chinese exporters follow suit and adapt their products accordingly.

The remaining two coefficients of column 1 include the foreign and SOE's export share by the regime. The coefficient of interest stays stable and significant at 1%. Both control variables positively affect product upgrading. The larger share of foreign firms in the export structure of a city generates spillover, which, in turn, can help expedite product upgrading of domestic firms. In the following four columns, we make sure that our results are robust to a shock in the destination country along with the exclusion of some cities and products. In the last three columns, we estimate export quality by setting the elasticity of substitution to 3, 5, and 10, respectively.

In column 4, we control for a potential endogeneity problem from the structural change

**Table 5.3: VAT export rebate and product's quality upgrading, baseline regression**

|   | Dependent variable: Product quality<br>(city/product/trade regime/year) |                      |                      |                      |                      |                      |                      |                      |                      |                      |
|---|---|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|   | Non eligible  | Eligible             | Baseline             | Shocks               | Balance              | Only 17%             | No zero rebate       | $\sigma = 3$         | $\sigma = 5$         | $\sigma = 10$        |
|   | (1)   | (2)                  | (3)                  | (4)                  | (5)                  | (6)                  | (7)                  | (8)                  | (9)                  | (10)                 |
| VAT refund <sub>k,t-1</sub>   | 0.044<br>(0.130)  | 0.310***<br>(0.044)  |                      |                      |                      |                      |                      |                      |                      |                      |
| Import tax <sub>k,t-1</sub>   | -0.018<br>(0.084)   | -0.203***<br>(0.023) |                      |                      |                      |                      |                      |                      |                      |                      |
| VAT refund <sub>k,t-1</sub> × Regime <sup>R</sup>                     |   |                      | 0.262***<br>(0.075)  | 0.261***<br>(0.075)  | 0.263***<br>(0.075)  | 0.259***<br>(0.075)  | 0.270***<br>(0.076)  | 0.224***<br>(0.074)  | 0.126**<br>(0.059)   | 0.071**<br>(0.036)   |
| Import tax <sub>k,t-1</sub> × Regime <sup>R</sup>                     |   |                      | -0.184***<br>(0.065) | -0.183***<br>(0.065) | -0.182***<br>(0.065) | -0.184***<br>(0.065) | -0.183***<br>(0.065) | -0.155***<br>(0.050) | -0.096***<br>(0.036) | -0.063***<br>(0.018) |
| Stock ntm destination country <sub>jk,t-1</sub>                       |   |                      | -0.008***<br>(0.003) | -0.098<br>(0.072)    | -0.009***<br>(0.003) | -0.009***<br>(0.003) | -0.008***<br>(0.003) | -0.008***<br>(0.002) | -0.007***<br>(0.002) | -0.065***<br>(0.020) |
| Stock ntm destination country <sub>jk,t-1</sub> × Regime <sup>R</sup> |   |                      | 0.010**<br>(0.005)   | 0.010**<br>(0.005)   | 0.010**<br>(0.005)   | 0.011**<br>(0.005)   | 0.010**<br>(0.005)   | 0.005**<br>(0.002)   | 0.006***<br>(0.002)  | 0.006***<br>(0.001)  |
| Foreign export share <sub>ck,t-1</sub> <sup>R</sup>                   |   |                      | 0.045**<br>(0.020)   | 0.061***<br>(0.019)  | 0.046**<br>(0.020)   | 0.048**<br>(0.020)   | 0.045**<br>(0.020)   | 0.052***<br>(0.015)  | 0.028**<br>(0.012)   | 0.023***<br>(0.008)  |
| SOE export share <sub>ck,t-1</sub> <sup>R</sup>                       |   |                      | 0.057***<br>(0.021)  | 0.093***<br>(0.021)  | 0.057***<br>(0.021)  | 0.054***<br>(0.021)  | 0.058***<br>(0.021)  | 0.062***<br>(0.018)  | 0.032**<br>(0.015)   | 0.027***<br>(0.009)  |
| product   | Yes   | Yes                  | No                   | No                   | No                   | No                   | No                   | No                   | No                   | No                   |
| City-product  | Yes   | Yes                  | No                   | No                   | No                   | No                   | No                   | No                   | No                   | No                   |
| City-product-regime   | No  | No                   | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Product-year  | No  | No                   | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Destination-year  | Yes   | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  | Yes                  |
| Observations  | 305,756   | 305,756              | 611,512              | 611,512              | 607,972              | 604,230              | 607,368              | 611,512              | 611,512              | 611,512              |
| R <sup>2</sup>  | 0.278   | 0.257                | 0.321                | 0.558                | 0.319                | 0.322                | 0.321                | 0.943                | 0.297                | 0.580                |

This table estimates eq(5.3). VAT refund is the share entitled to refund at the HS6 product. It is calculated by dividing the VAT rebate rate over the VAT rate. Note that the reference group for 'Regime' is the ordinary trade. It signifies the regime entitled to VAT refund as the treatment group. The control group is processing trade with supplied input, which is 'Non-Eligible' for a VAT refund. Sectors are defined in accordance with the Chinese 4-digit GB/T industry. Heteroskedasticity-robust standard errors. clustered at the product level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

in the demand of the importing country. This demand can be specific to the characteristics of the importing country. Preferences for better-quality goods in the importing country can affect the level of quality produced unrelated to the VAT refund. We introduce a new level of fixed effects to control demand shock: product–destination–year. The sign of the coefficient remains unchanged, albeit at a slightly lower level (.262 *versus* .261). Column 5 of table 5.3 keeps only cities available yearly in the sample. This exclusion does not alter the sign and significance of the main coefficient. The next two columns control for different VAT tax rates. In column 6, we keep only products with a discount rate of 17 percent throughout the period. In column 7, we drop the rebate when it equals zero. The results remain unaffected and reflect the stability coefficients of all the sub-samples. Columns 8 to 10 use a constant elasticity of substitution across sectors to estimate the quality. As the sigma increases, the results are robust with a lower effect of the VAT refund on the quality.

## 5.6.2 Heterogeneity effect

### Characteristics of the destination countries, products, and industrial size

The literature has documented different aspects of the exporting firm’s behavior. The heterogeneity of firms in the decision to export to certain types of markets, or whether or not they belong to a large/small industry, might affect their decision to engage in product upgrading differently. In this section, we examine the different impacts of the VAT refund on product upgrading. Let us suppose the product is exported to a developed economy or to a lesser developed economy. Is it capable of improving the horizontal/vertical differentiation of the product or does a large/small industry export it?

We use the data from the World Bank’s World Development Indicators and the definition of developing countries to split the data set according to income.<sup>14</sup> The table provides

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<sup>14</sup>The data set is available at this URL: [http://wits.worldbank.org/data/public/WITSCountryProfile-Country\\_Indicator\\_ProductMetada-en.xlsx](http://wits.worldbank.org/data/public/WITSCountryProfile-Country_Indicator_ProductMetada-en.xlsx).

information on the status of a country's income; such as 'Others', 'Low income,' 'Upper middle income','High income - non-OECD,' 'Lower middle income', and 'High income - OECD.' We group all countries with the label 'Low income' or 'Low Lower middle income' as 'LDC' or otherwise 'DC' (including HK).

Columns 1 and 2 of table 5.4 divide the countries of destination in accordance with the World Bank classification. Many papers (Bas and Strauss-Kahn 2015; Hallak 2006; Khandelwal et al. 2013; Schott 2004) have empirically demonstrated that richer countries consume more 'high-quality' goods, which gives firms an incentive to improve their products for high-income markets to increase their margin in a significant manner (Manova and Zhang 2012). The first two columns confirm this hypothesis. When the government decides to raise the VAT refund, product upgrading remains specific to exports that reach developed economies. Although negative, the coefficient for the interaction between the regime and VAT refund in column 1 (least developed countries) remains insignificant. The coefficient is positive and significant for the developed countries (column 2), with a stronger elasticity than the baseline regression. The coefficient is .2 percentage points higher than our baseline estimate (.28 *versus* .26).

The degree of product differentiation is likely to affect product upgrading differently. It seems reasonable that products with a broad scope of differentiation will benefit more from VAT refunds than homogeneous products. To distinguish the HS6 products, we classify them according to the methodology of Rauch (Rauch 1999).<sup>15</sup> In column 3, we only take homogeneous products into consideration. In column 4, we consider the heterogeneous products. The coefficient shows that increasing the refund on products classified as heterogeneous positively affects product upgrading and does not have any statistical effect on homogeneous goods. According to the findings, the refund does not uniformly affect all products and policymakers should pay close attention to the type of goods targeted.

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<sup>15</sup>An R package provides the list of products from Rauch along with the concordance between classification system and is available at <https://github.com/cran/concordance>.

**Table 5.4: VAT export tax, firm's quality upgrading, and characteristics of the destination countries, products, and cities**

|  | Dependent variable: Product quality<br>(city/product/trade regime/year) |                      |                   |                      |                    |                      |
|--|---|----------------------|-------------------|----------------------|--------------------|----------------------|
|  | LDC   | DC                   | Homogeneous       | Heterogeneous        | Small              | Large                |
|  | (1)   | (2)                  | (3)               | (4)                  | (5)                | (6)                  |
| VAT refund $_{k,t-1} \times \text{Regime}^R$                     | -0.036<br>(0.326)   | 0.285***<br>(0.075)  | 0.325<br>(0.300)  | 0.280***<br>(0.078)  | 0.214**<br>(0.091) | 0.378***<br>(0.134)  |
| Import tax $_{k,t-1} \times \text{Regime}^R$                     | -0.479**<br>(0.237)   | -0.187***<br>(0.065) | 0.067<br>(0.172)  | -0.184***<br>(0.067) | -0.224<br>(0.173)  | -0.176**<br>(0.068)  |
| Stock ntm destination country $_{jk,t-1}$                        | -0.056<br>(0.044)   | -0.008***<br>(0.003) | 0.011<br>(0.010)  | -0.009***<br>(0.003) | -0.004<br>(0.003)  | -0.015***<br>(0.004) |
| Stock ntm destination country $_{jk,t-1} \times \text{Regime}^R$ | 0.022<br>(0.037)  | 0.010*<br>(0.005)    | -0.012<br>(0.016) | 0.011**<br>(0.005)   | 0.011<br>(0.007)   | 0.006<br>(0.004)     |
| Foreign export share $^R_{ck,t-1}$                               | 0.050<br>(0.101)  | 0.044**<br>(0.020)   | 0.087<br>(0.067)  | 0.044**<br>(0.020)   | 0.039<br>(0.026)   | 0.059**<br>(0.026)   |
| SOE export share $^R_{ck,t-1}$                                   | -0.102<br>(0.108)   | 0.061***<br>(0.021)  | 0.004<br>(0.083)  | 0.059***<br>(0.021)  | 0.052<br>(0.033)   | 0.109***<br>(0.027)  |

This table estimates eq(5.3). VAT refund is the share entitled to refund at the HS6 product. It is calculated by dividing the VAT rebate rate over the VAT rate. It is noteworthy that the reference group for 'Regime' is the ordinary trade. It refers to the regime entitled to VAT refund as the treatment group. The control group is processing trade with supplied input, which is 'Non-Eligible' for a VAT refund. Sectors are defined in accordance with the Chinese 4-digit GB/T industry. LDC and DC are defined according to the World Bank country classification. Homogeneous and heterogeneous goods are defined according to the official list of goods' classification from Rauch (Rauch 1999). Small and large are computed based on the total quantity exported by city-HS4. When the total exports by city-HS4 are higher than the city average, the city-industry is considered large. Heteroskedasticity-robust standard errors clustered at the product level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

Finally, the industrial size also matters in the export market. Firms operating in industries with a low share of national exports may have less incentive to promote product upgrading than larger industries. We assess if the industry size plays a significant role in product upgrading. We define an industry as large (*versus* small) when the total exports computed at the city-HS4 level are larger (*versus* lower) than the 75th percentile within the city using 2002's export data.<sup>16</sup> The predictions are in line with the theories of trade (Manova and Zhang (2012)). Larger industries export goods of better quality than smaller industries, which translates to the capacity to upgrade following an increase in the VAT refund.

### **VAT rebate policy and the promotion of targeted industries**

China's 10th and 11th Five-Year plans (2001-2005 and 2006-2010, respectively) emphasized two main objectives. On the one hand, energy became a central concern of the plans. On the other hand, the promotion of export embedded with higher added-value and high technology products was expected.

First, the 10th FYP introduced an environmental target regarding SO<sub>2</sub> emissions for the very first time. Specifically, a reduction of 10% of sulfur dioxide (SO<sub>2</sub>) at the end of 2005 compared with the level of 2001 was expected. Encountering strong difficulties enforcing the environmental policy, the Party decided to better engage the provincial leaders in implementing the law. Starting in 2006, each province was assigned a maximum level of pollution permitted until the end of 2010. Failure to meet the environmental objectives led to severe consequences for the governors, such as revocation or career downgrades. In a document from the United Nations Framework Convention on Climate Change, China declared in 2007 that it would "deepen institutional reform of foreign trade in controlling the export of energy-intensive, pollution-intensive and resource-intensive products, to formulate an import and export structure favorable to promote a cleaner and optimal energy mix".<sup>17</sup>

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<sup>16</sup>Results are robust to other thresholds such as mean, median, and 90th percentile.

<sup>17</sup>The official statement is available at this url: <https://www.fmprc.gov.cn/ce/cgvienna/eng/xw/>

As pointed out by Gourdon et al. (2016), the VAT rebate policy was used to reduce the export of water polluted sectors and air polluting sectors, which is in consonance with the environmental framework set by China after 2001. In the context of our analysis, we expected the VAT rebate to be effective on product upgrading in less polluted industries only.

Secondly, promoting high-value-added products and the advancement and innovation of science and technology is central to Chinese economic development. A paper from Gourdon et al. (2016) points out that the Chinese government cherry-picked products in order to support sophisticated high-technology products through the change in the VAT rebate. However, there is no evidence to suggest that product upgrading occurred following a change in the rebate.

Other than the terms of trade, the VAT rebate policy has two other major objectives to develop the Chinese economy. First, the policymaker set ambitious environmental targets. As one of the fundamental turns taken by Beijing in 2001 during the 10th FYP (2001-2005), an official pollution reduction was set at the national level.<sup>18</sup> The policy was re-conducted during the 11th FYP (2006-2010), after which the target was broken down at the province level, made mandatory, and career-related to the governors. Secondly, the Chinese government strongly encouraged the reorientation of exports toward higher, value-added products, and sophisticated, high-technology products.

In table 5.5, we test the policy's effectiveness by considering its environmental aspect and the capacity to upgrade products that are complex by nature and require a range of know-how in manufacturing, including the coordination of a range of highly skilled individuals.

In columns 1 and 2, we confirm that the change in refund is ineffective for products exported in polluted sectors, which should be in line with recent environmental policies. The VAT refund signifies one of the environmental measures that the government is undertaking

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t326729.htm.

<sup>18</sup>During the 10th Five-Year Plan (2001-2005), the first environmental target was enacted, stipulating a reduction of 10% of the total SO<sub>2</sub> emission in 2005 from 2000 levels.

**Table 5.5: VAT export tax, firm's quality upgrading, and the promotion of targeted industries**

|  | Dependent variable: Product quality<br>(city/product/trade regime/year) |                      |                     |                      |                    |                      |
|--|---|----------------------|---------------------|----------------------|--------------------|----------------------|
|  | Polluted intensive  |                      | High tech           |                      | RD oriented        |                      |
|  | (1)   | (2)                  | (3)                 | (4)                  | (5)                | (6)                  |
|  | Yes   | No                   | Yes                 | No                   | Yes                | No                   |
| VAT refund $_{k,t-1} \times \text{Regime}^R$                     | 0.342<br>(0.046)  | 0.264***<br>(0.022)  | 0.439***<br>(0.042) | 0.202**<br>(0.022)   | 0.389**<br>(0.041) | 0.348***<br>(0.021)  |
| Import tax $_{k,t-1} \times \text{Regime}^R$                     | -0.236<br>(0.205)   | -0.181***<br>(0.067) | 0.181*<br>(0.098)   | -0.290***<br>(0.072) | -0.087<br>(0.180)  | -0.241***<br>(0.067) |
| Stock ntm destination country $_{jk,t-1}$                        | -0.015<br>(0.010)   | -0.005*<br>(0.003)   | -0.001<br>(0.005)   | -0.010***<br>(0.003) | -0.001<br>(0.004)  | -0.005<br>(0.003)    |
| Stock ntm destination country $_{jk,t-1} \times \text{Regime}^R$ | 0.015<br>(0.010)  | 0.010*<br>(0.006)    | 0.023*<br>(0.012)   | 0.005<br>(0.003)     | 0.019*<br>(0.010)  | 0.007**<br>(0.004)   |
| Foreign export share $_{ck,t-1}^R$                               | -0.012<br>(0.028)   | 0.062***<br>(0.026)  | 0.065<br>(0.057)    | 0.035<br>(0.020)     | 0.061<br>(0.052)   | 0.021<br>(0.018)     |
| SOE export share $_{ck,t-1}^R$                                   | 0.004<br>(0.208)  | 0.075***<br>(0.085)  | 0.088<br>(0.154)    | 0.033*<br>(0.086)    | 0.083<br>(0.184)   | 0.026<br>(0.087)     |
| City-product-regime  | Yes   | Yes                  | Yes                 | Yes                  | Yes                | Yes                  |
| Product-year   | Yes   | Yes                  | Yes                 | Yes                  | Yes                | Yes                  |
| Destination-year   | Yes   | Yes                  | Yes                 | Yes                  | Yes                | Yes                  |
| Observations   | 153,006   | 458,506              | 142,372             | 469,140              | 201,344            | 410,168              |
| R <sup>2</sup>   | 0.371   | 0.313                | 0.333               | 0.324                | 0.325              | 0.335                |

This table estimates eq(5.3). VAT refund is the share entitled to refund at the HS6 product. It is calculated by dividing the VAT rebate rate over the VAT rate. Note that the reference group for 'Regime' is the ordinary trade. It refers to the regime entitled to VAT refund as the treatment group. The control group is processing trade with supplied input, which is 'Non-Eligible' for a VAT refund. Sectors are defined in accordance with the Chinese 4-digit GB/T industry. The nomenclature to classify the sectors into polluting and less polluting sectors come from He et al. (2020). High complexity products denote products requiring technical skills, a range of know-how in manufacturing, and high-level technology. Values are downloaded from the Product Complexity Index. Column (3) groups all products with a value of Product Complexity Index above 0.78 (i.e., the 75th percentile). All sectors with a total R&D intensity higher than the third decile value are classified as "Yes," hence designated as RD-oriented industry; otherwise, "No." Heteroskedasticity-robust standard errors clustered at the product level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.



to reduce polluting activities. We use the nomenclature of He et al. (2020) to classify the sectors into polluting and less polluting sectors. According to the author, the 16 polluting industries defined by the MEP comprise roughly 80% of China's total industrial COD emissions. The classification uses the 3-digit GBT industry classification. Therefore, we are required to map these industries into the HS code. We use the concordance table between GBT sectors and HS6 products from Brandt et al. (2017).

The interaction term coefficient between the VAT refund and the regime is positive while not significant for the products exported by polluting industries. However, the VAT refund effectively promotes product upgrading in sectors emitting fewer pollution emissions. The results are aligned with our expectations and confirm that the VAT policy can work in tandem with the environmental policies created by the government.

In columns 3 and 4, we evaluate the potential effects of a refund on product upgrading when distinguishing sophisticated products from less sophisticated products. Specifically, we use product complexity ranking computed by Hidalgo and Hausmann (2009) using 2002 values.<sup>19</sup> Product complexity refers to the diversity and sophistication of the productive know-how required to produce a product. The most complex products require technical skills, a range of know-how in manufacturing, and high-level technology. We define a product as complex if the value of the product complexity index is above the 75th percentile (value above 0.78).<sup>20</sup> The results in column 3 suggest that the refund has a stronger effect on complex products than on less complex products (.439 *versus* .202) The results hold if we use different thresholds (.8, .9, and .95).<sup>21</sup> These findings prove to be very valuable as the effect of a refund reinforces the potential of such products. Complex products not only have high added value but are also more expensive and imported by rich countries (i.e., willing to

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<sup>19</sup>The data set is available at this url: `blob:https://atlas.cid.harvard.edu/25f289a2-ef9a-43f9-ade7-d33aa0007453`.

<sup>20</sup>The minimum value for the product complexity index is -2.89, and the maximum is 2.56. Around 312 products are classified as highly complex, with a few examples: Silicone in primary forms, machines, and mechanical appliances, apparatus based on the use of X-rays, halogens, sulfates, nitrates, etc.

<sup>21</sup>Estimations available upon request.

pay higher prices). Furthermore, complex products have a strong relationship with growth and export growth. For this reason, the refund pushes upgrading further, reinforcing China's comparative advantages in those products.

In the last two columns, we extend our analysis to evaluate whether or not sectors engaged in R&D will benefit more from the refund. Specifically, we use the firm's census data collected by the National Bureau of Statistics (NBS) to construct the sector *R&D* intensity (*R&D* expenditure over output). The NBS collects information on domestic as well as foreign firms with sales revenues above 5 million RMB. It includes only manufacturing sectors. Basic information, such as ownership status, corporate address, output, exports, employment, four-digit Chinese Industry Classification, and financial information, is included. The firm's census data provides information on the production, employment, and financial structure of the majority of firms in China. Data from 2004 includes the amount spent on *R&D*. We aggregate both the *R&D* expenditure and output at the two digits industry level<sup>22</sup> and then classify a sector as *R&D* intensive if the *R&D* intensity is larger than the 75th decile. Similar to the polluted *versus* less polluted classification, we use the concordance table between GBT sectors and HS6 products from Brandt et al. (2017) to map the 2-digit GBT sectors to the HS6 product. Column 5 estimates our baseline equation sub-setting only *R&D* oriented sectors. The interaction coefficient between the VAT refund and the rebate is found to be positive and significant. The results are encouraging because they provide evidence of the positive role of the VAT refund in sectors engaged in *R&D*. In contrast, the other sectors still enjoy the VAT refund as a way to promote product upgrading (column 6), albeit to a lower extent than the *R&D* intensive sectors.

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<sup>22</sup>Not all industries spend money on *R&D*, so we use the HS2 level to make more observations in the *R&D* oriented classification.

## 5.7 Mechanism

We leverage the richness of the Chinese custom dataset to investigate the underlying mechanisms between VAT rebates and product upgrading. As emphasized in section 5.4, one mechanism can potentially affect the quality of products following an adjustment of the VAT rebate. Credit constraints can restrict product upgrading, as demonstrated by the model of Fan et al. (2015).

### 5.7.1 Credit constraint and product upgrading

We are interested in understanding whether or not the positive effect of VAT rebate on adjusted quality interacts with credit constraints for the firm engaged in ordinary trade. We expected to see a positive sign from the triple interaction term between VAT rebate, regime, and credit constraint. The underlying idea is that constrained firms use the new liquidity from an increase in the rebate to make investments leading to product upgrading. Firms facing tighter credit constraints induce lower quality, but it is possible to offer this outcome by increasing cash stemming from the increase in the rebate. We estimate the following equation to test our assumption:

$$\begin{aligned}
 \text{Quality}_{c,k,j,t}^R &= \alpha \text{VAT Refund}_{k,t-1} \times \text{Eligibility}_{c,k,j,t}^R + \\
 &\quad \alpha \text{VAT Refund}_{k,t-1} \times \text{Eligibility}_{c,k,j,t}^R \times \text{credit constraint}_i + \\
 &\quad \beta \text{Import tax}_{k,t-1} \times \text{Eligibility}_{c,k,j,t}^R + \\
 &\quad \beta \text{NTM}_{k,j,t-1} \times \text{Eligibility}_{c,k,j,t}^R + \\
 &\quad \theta X_{c,s,t-1}^R + FE_{c,k}^R + FE_{k,t} + FE_{j,t} + \epsilon_{c,k,j,t}^R
 \end{aligned} \tag{5.5}$$

where the dependent variable,  $\text{Quality}_{c,k,j,t}^R$ , denotes the estimated quality calculated at the HS6 product level  $k$ , exported by city  $c$  under the trade regime ordinary or processing  $R$  to country  $j$  at year  $t$  from the methodology of Khandelwal et al. (2013). We isolate the effect of the VAT refund by interacting with a dummy variable capturing the trade

status,  $Eligibility^R$  that takes the value of one if the flow is eligible for a refund and zero otherwise. We add another level of interaction with the credit constraint.  $credit\_constraint_i$  is a dummy variable taking the value of 1 if one of the four measurements (*external finance*, *Asset tangibility*, *RD intensity* and *liquidity needs*) defined in section 5.5.2 is above the median indicating a constrained industry  $i$ .<sup>23</sup>

Our specification includes several fixed effects to mitigate potential problems from confounding factors. First, we add a city-product-regime fixed effect,  $FE_{c,k}^R$  to capture all the time-invariant factors affecting products exported by city  $c$  across the regime. Next, we control for the product year dummy,  $FE_{k,t}$ , thus providing an additional level of control, and encompassing all the shocks and developments in the economies to which China exports. Our last fixed effect control is for any time difference taking place between the destination country, such as a difference in demand of product  $k$  with  $FE_{j,t}$ . We then add an interaction between import taxes,  $Import\ tax_{k,t-1}$ , and the trade regime,  $Eligibility^R$ , to control the effect of trade openness on quality (Bas and Strauss-Kahn 2015). Finally, we control for the export share by export trade flow's ownership (domestic *versus* foreign and private *versus* SOE) under both regimes. The standard error is clustered at the product level, and the term  $\epsilon_{c,k,j,t}^R$  signifies the error.

Table 5.6 reports the results of equation 5.5. Column 1 uses the variable *external finance* as a proxy for credit constraint, column 2 uses *liquidity needs*, column uses 3 proxy credit constraint with *Asset tangibility* and column 4 uses *RD intensity*.

The coefficient of interest is the triple interaction term, which indicates whether or not eligible firms in constrained industries use the VAT refund to engage in product upgrading. All coefficients are positive and significant at 1% and fluctuate around .4 to .6. We interpret these results as follows: a firm with higher credit needs increases quality-adjusted after an increase in the VAT rebate. The results are in line with the model's prediction of Fan et al.

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<sup>23</sup>Note that for the variable *Asset tangibility*, we use the value below the median because a larger value of *Asset tangibility* indicates less constraints while larger values for the three other metrics imply more financial constraints.

**Table 5.6: VAT export tax, firm's quality upgrading, and credit constraint**

|   | Dependent variable: Product quality<br>(city/product/trade regime/year) |                      |                      |                      |
|---|---|----------------------|----------------------|----------------------|
|   | (1)   | (2)                  | (3)                  | (4)                  |
|   | Ext. Fin  | Liquidity needs      | Asset Tang.          | RD intensity         |
| VAT refund $_{k,t-1} \times \text{Regime}^R$                              | 0.140**<br>(0.069)  | 0.195***<br>(0.065)  | 0.117*<br>(0.068)    | 0.162*<br>(0.093)    |
| VAT refund $_{k,t-1} \times \text{Regime}^R \times \text{Credit needs}_k$ | 0.444***<br>(0.103)   | 0.421***<br>(0.117)  | 0.638***<br>(0.113)  | 0.148<br>(0.100)     |
| Import tax $_{k,t-1} \times \text{Regime}^R$                              | -0.176***<br>(0.032)  | -0.178***<br>(0.032) | -0.174***<br>(0.032) | -0.183***<br>(0.032) |
| Stock ntm destination country $_{jk,t-1}$                                 | -0.008***<br>(0.002)  | -0.008***<br>(0.002) | -0.008***<br>(0.002) | -0.008***<br>(0.002) |
| Stock ntm destination country $_{jk,t-1} \times \text{Regime}^R$          | 0.010***<br>(0.002)   | 0.010***<br>(0.002)  | 0.010***<br>(0.002)  | 0.010***<br>(0.002)  |
| Foreign export share $_{ck,t-1}^R$  | 0.045***<br>(0.014)   | 0.045***<br>(0.014)  | 0.045***<br>(0.014)  | 0.045***<br>(0.014)  |
| SOE export share $_{ck,t-1}^R$  | 0.054***<br>(0.015)   | 0.055***<br>(0.015)  | 0.056***<br>(0.015)  | 0.056***<br>(0.015)  |
| City-product-regime   | Yes   | Yes                  | Yes                  | Yes                  |
| Product-year  | Yes   | Yes                  | Yes                  | Yes                  |
| Destination-year  | Yes   | Yes                  | Yes                  | Yes                  |
| Observations  | 611,512   | 611,512              | 611,512              | 611,512              |
| R <sup>2</sup>  | 0.321   | 0.321                | 0.321                | 0.321                |

This table estimates eq(5.5). VAT refund is the share entitled to refund at the HS6 product. It is calculated by dividing the VAT rebate rate over the VAT rate. Note that the reference group for 'Regime' is the ordinary trade. It refers to the regime entitled to VAT refund as the treatment group. The control group is processing trade with supplied input, which is 'Non-Eligible' for a VAT refund. Sectors are defined in accordance with the Chinese 4-digit GB/T industry. credit constraint $_i$  is a dummy variable taking the value of 1 if the industry is financially dependent and is measured using one of the four following variables (*external finance*, *Asset tangibility*, *RD intensity* and *liquidity needs*). Heteroskedasticity-robust standard errors clustered at the product level appear in parentheses. \* Significance at 10%, \*\* Significance at 5%, \*\*\* Significance at 1%.

(2015), where tighter credit constraints force firms to produce lower quality. We extend this model by providing a counter-balance force to credit constraint and adjusted quality. Firms use this excess cash flow to invest (in fixed assets or innovative projects) by increasing the refund granted to ordinary traders, thus improving the quality. The interaction between VAT refunds and the regime is also positive and significant. This confirms our baseline results where higher refund for eligible traders increases the quality.

## 5.8 Conclusion

In this study, we evaluated the impact of a major industrial policy in China referred to as the VAT tax system on the product upgrading of exported products within city. We used the duality in the trading system to isolate the causal impact between the VAT refund and product upgrading. Transaction trade in China entitles some firms to partially or fully claim back VAT refunds. This distinction allows us to obtain an almost natural group that is not subject to the tax refund. Our sample consists of ordinary and processing companies exporting 2742 HS6 products from 192 cities to 205 countries from 2003 - 2010. According to our findings, an increase in the VAT refund will likely promote product upgrading. Our results also reveal that ordinary traders comply with the importing countries' regulations. The use of non-trade barriers to raising the standard of the country of import compels ordinary traders to improve the quality. Then, we borrow the model of Fan et al. (2015) to explain that constrained industries use the new liquidity stream from the VAT refund to engage in product upgrading. Firms in industries with tighter credit constraints would choose lower product quality. A positive change in the VAT refund will not only offset the credit constraints but also promote the firm's investment. We use four different measures to proxy for credit needs: external finance dependence, liquidity needs, asset tangibility, and R&D intensity. Our model results indicate that the VAT refund alleviates the credit constraints and explains the quality improvement mechanism.

This paper makes another contribution in that it leverages the dimensions of the export data to allow us to distinguish the circumstances under which the product upgrading has a larger probability of occurring. We demonstrate that exporters better utilize a refund on product upgrading when the product is imported by a developed economy, has the capacity to be differentiated (vertically or horizontally), and belongs to a large industry.

Chinese policymakers formally introduced environmental objectives under the 10th and 11th FYP, respectively. The party leaders put a lot of weight on promoting products embedded with high added value or technological content. Meanwhile, they underscored the willingness to downscale the export share of energy-intensive or polluting industries. We evaluated if the environmental and economic concerns impact product upgrading. The results suggested that the VAT refund is effective only for products produced in "cleaner" industries, requiring technical skills and a range of know-how in manufacturing high-level technology or engaging in R&D activities. This implies that although the VAT rebate system discriminates against exporters, it is proven to be an efficient way of promoting product upgrading, particularly in more environmentally friendly industries and sophisticated products.

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# Conclusion

China is particularly affected by environmental disasters and climate change. China is often quoted as one of the largest polluters globally and responsible for more than 27% of the total global emissions of greenhouse gas. In 2015, China signed the Paris agreement and pledged to be carbon neutral by 2060. There are plenty of reasons for caution because of the root of the Chinese development path and the large appetite for energy. Coal consumption has stabilized from 2013 to 2017, mainly driven by a push of the central government to improve the poor air quality. Coal consumption began to rise again in recent years to counterbalance the economic slowdown. The Chinese economy needs to consume lots of energy and coal to fuel industrial growth. To align with the environmental objectives depicted by the central government, China needs to go beyond the reduction of consumption of coal, which is one of the most pollution factors. Reality is proven different; more construction permits for coal-fired power plants in the first six months of 2020 have been granted than in 2018 and 2019. The addiction to coal is so important from an energy supply and security point of view; therefore, other channels should be in place to manage the pollution in China.

Coal consumption is the primary driver of pollution, but financial misallocation is also part of it.

In the early twenties, the Chinese government attempted to introduce more formally a pollution reduction target imposed nationally. The failure of regulation was devastating for the environment. The level of SO<sub>2</sub> released into the atmosphere more than doubled between 2001 and 2006. Acknowledging the failure of the policy, the government decided to break down the pollution target at the province level while keeping the national objective of a 10% reduction. The government also attributed the environmental objective's success and failure to the local representative's career. The pollution-incentive target system pushed the local government to engage in reducing emissions of pollution. However, government efforts are attenuated in cities where the presence of SOEs is substantial. A large presence of SOE reduces the effectiveness of an environmental policy as the firm's objective is focused

on employment rather than pollution emission. The poor resource management from SOE, paired with the soft budget constraint, prevents them from complying with the regulation.

Credit constraint is prevalent in China, pressing private firms to find alternative financing resources to sustain their development. Credit constraints pose a problem from an environmental point of view because they distort the allocation of assets. credit constraints distort the composition of assets towards over-investment in tangible assets, which can be pledged as collateral, thereby increasing the intensity of emissions. The availability of internal cash flow offsets the binding credit constraint and is associated with lower pollution emissions. In this situation, firms with more internal finance are less likely to invest in tangible assets and more likely to use their cash flow to fund technological innovations, and R&D. internal finance causes an improvement of the TFP, which in turn reduces pollutant emissions. companies better endowed with internal financing are more likely to purchase pollution abatement equipment.

Financial development is one of the most effective ways to reduce credit constraints on private enterprises. Financial development through deregulation and a larger inflow of loans lead to a reduction in the emission of toxic discharge. Reducing pollution emissions comes with cheaper and easier access to finance, leading firms to invest in technology that can change the production process, affecting both productivity and energy consumption, indirectly reducing the emission of pollution. Finally, firms have re-balanced their asset allocation when they have easier access to finance, and we rule out the scale effect hypothesis.

After joining the WTO in 2002, exports increased exponentially and pollution emissions simultaneously. The Chinese government frequently uses industrial policy to orientate the manufacturing output and the pattern of trade. VAT rebates are among the most used tools by the government to manipulate the term of trade. VAT rebates have undergone many adjustments during the 10th and 11th FYP. The adjustments followed two main guidelines.

On the one hand, energy became a central concern of the plans. On the other hand, the promotion of export embedded with higher added-value and high technology products is expected. Two key questions arise from the VAT rebate policy: 1) how effective is the VAT rebate policy on product upgrading; 2) how the VAT rebate policy can impact product upgrading. Our results show an increase in product upgrading in response to an increase in VAT refund. The industries facing tighter credit constraints cause firms to choose lower product quality. VAT refunds provided a counter-balance force to credit constraints leading firms to adjust quality. By increasing the refund granted to ordinary traders, firms use this excess cash flow to invest (in a fixed asset or innovative project) and improve the quality. This effect is reinforced for products exported to developed countries, heterogeneous products, or from larger industries. VAT refund is effective only for products produced in "cleaner" industries, for products requiring technical skills, a range of know-how in manufacturing, and high-level technology or engaging in R&D activities. Chinese exporters comply with the change in regulation in the import market by adjusting the quality upward.