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Energy use and exporting: an analysis of Chinese firms

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Abstract
As global emissions increase with global trade, there is a critical need to understand the importance of energy use in export-oriented manufacturing activities in emerging economies. We investigate this issue by examining whether the extent of firms' involvement in exporting is associated with the energy-intensiveness of their production activities. We use data from a survey of Chinese firms, officially classified as users of 'advanced' technologies. Although in recent years China has been attempting to discourage exports of energy- and pollution-intensive products, our results show a positive association between firms' energy-use intensity and their exporting. This relationship exists across industries with different levels of technological sophistication, but is particularly salient in industries characterized by high energy-use intensity. We discuss the theoretical and policy implications of these findings.

Keywords Energy intensity · Export · China

JEL F18 · H23 · Q56 · Q58

1 Introduction

In the last 25 years, China's economic integration with the world economy has increased alongside its emergence as a leading exporter of manufacturing products (WDI 2021). It is well-known that the availability of a vast pool of low-waged workers – both low skilled employees and middle-range technicians – makes China an attractive location for large western companies' outsourcing of production and assembly of even high-end products, such as *iPhones* (Zhou 2008; Nahm and Steinfeld 2014). In 2009, China was the world's largest manufacturing economy,

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surpassing the US, and in 2012 and 2019 accounted for 18% and 28% respectively of global manufacturing exports (WDI 2021).

This rapid industrialization and internationalization has been accompanied by exponential increases in energy consumption in China and, by the late 1990s, it had become a net importer of energy (WDI 2021). Although green energy production has experienced a rapid increase in China,[1] carbon emissions per capita more than tripled over the period 1990–2018, from 2.2 metric tons to 7.35 metric tons, representing 30% of world emissions of carbon (WDI 2021). Electricity production, which relies heavily on coal and oil, has been a major contributor: in 2015 more than 75% of electricity production was based on fossil fuels (WDI 2021). Carbon emissions in China stem, also, from the direct use of coal, oil, and gas in firms' production processes. Exporting account for almost a quarter of China's total emissions (Wang and Watson 2008). This raises the important question of whether firms' energy-use behaviour differs depending on whether it is related to production for foreign markets or the domestic market.

Several scholars have focused on the potential increases in emissions associated with the increased volume of exports from China and other emerging economies (Levinson and Taylor 2008; Sato 2014; Brandi et al. 2020). This relationship, at the sectoral level, has been the subject of several cross-country studies whose results show that exports from China (e.g., Lopez et al. 2013; Zhao et al. 2016) and from the emerging economies, more generally (Simas et al. 2015), have boosted global emissions. While this stream of work highlights the negative consequences for the environment of increased exports from emerging economies, the sectoral nature of these studies hides the heterogeneity among firms in terms of their production and technologies (Simas et al. 2015; Dechezleprêtre and Sato 2017). As Sato (2014, p. 845) puts it, 'the sector's trade composition does not reflect the production composition, or where technology is differentiated between export-demand and domestic-demand oriented production'. Critically, we do not know whether in an emerging country, the energy-use behaviour of firms in their production for domestic and export markets is similar or dissimilar. This is an important issue because it could help to explain whether emissions associated with exporting from emerging economies simply reflect the production technologies in use in these economies. In this case, firms with different levels of exports are unlikely to differ significantly in terms of their energy use. Alternatively, the association between emissions and exports may reflect other factors, such as environmental awareness of foreign customers or potential foreign preferences for products that involve low-cost, resource-abundant production techniques, which may make production for exporting less or more energy intensive than production for the domestic market. Investigating these contrasting possibilities requires a firm-level analysis to identify the presence and nature of the association between export orientation and energy use.

[1] Since the mid-2000s, China has had the world's largest renewable power capacity (whether including hydro power or not) (REN21, 2010, 2014) and Chinese firms lead the global wind turbine and solar PhotoVoltaic (PV) technology markets (Nahm and Steinfeld 2014). China also hosts the largest number of Kyoto mechanism projects aimed at reducing carbon emissions (Bodas Freitas et al. 2012).

The large body of work on firm exports highlights several characteristics specific to exporting firms, in particular in emerging economy contexts where it has been shown that exporting firms have certain attributes which differ from those considered representative of their industries (Aw and Hwang 1995). Thus, in this respect, learning and innovation is widely seen as a critical ingredient for success in foreign markets, compared to domestic markets (Clerides et al. 1998a, b; Salomon and Shaver 2005; Wagner 2007; Wagner and Zahler 2015; Xie and Li 2018). However, although these works add to our understanding of the characteristics of exporters, they do not consider potential differences in intensity of energy use between production activities geared towards exports and those aimed at domestic consumers. In today's world, where emissions are growing in line with trade (Lopez et al. 2013; Zhao et al. 2016), this has become an urgent issue.

This paper responds by investigating whether and to what extent firms' energy use is associated with their degree of engagement in exporting compared to production for the domestic market. We propose that factors related to the complexity and sophistication of exported products, environmental regulation, and low-cost, resource-intensive production technologies may contribute to a positive association between energy intensity in production and export intensity in emerging countries. We examine the nature of the association between energy intensity and export intensity across industries that differ in terms of their technologies and use of energy. Our analysis exploits data on a sample of 468 firms, classified by the Ministry of Science and Technology of China as users of new or 'advanced' technologies. The firms in our sample are located in Hebei province, where the average price of electricity supplied to industry is not the cheapest in China (Berkeley Lab 2014). Since, arguably, these firms are more focused on innovation than the 'average' Chinese manufacturing firm, it is reasonable to assume that the association between energy intensity and exports in the average manufacturing firm will be at least as strong as in our sample of firms. Most manufacturing firms in emerging economies, including China, rely on old, less energy-efficient technologies (Clerides et al. 1998a, b; Wagner 2007; Simas et al. 2015).

Our econometric analysis controls for industry and numerous firm-level factors and shows that energy-intensive firms are more likely to export a greater share of their production than firms using relatively low energy-intensive technologies.[2] We find a similar pattern across industries with different levels of technological sophistication, but it is less pronounced in industries with low energy use. In Sect. 6, we discuss the theoretical and policy implications of our findings.

The paper is organized as follows. Section 2 describes the empirical context of our study, including the evolution and pattern of energy use, trade and the regulatory framework in China. Section 3 discusses the export-orientation of emerging economies and reviews some firm-level studies on the drivers of exporting activity.

[2] It might be that the association between energy intensity and export competitiveness might be hiding potentially greater innovativeness of energy-intensive, export-oriented firms. However, we found no positive association between energy intensity and export intensity, and firm innovation performance (see Sect. 5).

We review current understanding related to the link between exports and energy use and formulate our research questions. Section 4 presents the data and discusses the model selection strategy. Section 5 reports the results of our analysis and Section 6 concludes the paper.

2 Contextual background: energy use in Chinese industries

Chinese industry, which accounts for about 90% of total energy consumption in the country, confronts relatively high energy prices compared with their counterparts in many other parts of the world. For example, compared to the US, energy prices charged to industry in China are between 34 and 49% higher, depending up on the provinces and states being compared and the types of consumer (BLS and Tractus 2016). In particular, in China, electricity, the most frequent source of energy for Chinese manufacturing firms (China Power Project 2019), is more costly than in many advanced economies. Research by Berkeley Lab shows that in 2011, the average price of a kWh of electricity in China was 5.6 GB pence (0.59 RMB) (although 10.65 GB pence in Japan and 9.8 GB pence in Germany), compared to 4.25 GB pence in the US, 3.55 GB pence in Norway and 3.66 GB pence in Korea (BEIS 2013). A study by Ecofys, Fraunhofer-ISI and GWS (2015) further shows that electricity prices for energy-intensive activities[3] are the third most expensive in China (6.37 EUR cents) after Japan (12.42 EUR cents) and Italy (7.57 EUR cents), compared to much lower prices in Germany (4.69 EUR cents), France (4.2 EUR cents) and Canada (3.24 EUR cents).[4] It should be noted that, production of electricity based on abundant resources, such as coal, has been less attractive since the establishment in 2004 of the 'coal-electricity price linkage' mechanism, which allows fluctuations in the price of electricity to reflect changes in the partly competitive coal price (International Energy Charter 2018).

Over the last 25 years, China has invested heavily in energy production and, particularly, 'clean' sources of energy such as hydroelectric power in the late 1990s, wind farms in the mid-2000s and, most recently, solar PV farms. China has the world's highest installed capacity of renewable energy (REN21 2018). However, its rapid industrialization meant that, by 1998, demand for energy was outstripping domestic supply and, in 2014, energy imports accounted for 15% of total energy used (WDI 2021). Although the share of renewables in total electricity production in China increased from 16% in 2000, to 20% in 2012, and 26% in 2018, oil, gas and coal sources dominate energy consumption in China and their share increased from about 70% in 2000 to 88% in 2015 (WDI 2021). Thus, despite efforts to boost green electricity, electricity consumption in China contributes to a large proportion of the country's carbon emissions.

[3] The six main energy-intensive sectors in China are petroleum, chemicals, ferrous and non-ferrous metals, non-metallic mineral products, electric and heat power. These activities accounted for 50% of China's total energy consumption in 2016 (International Energy Charter 2018).

[4] "Since June 2004, a differential electricity price has been applied to energy-intensive industries, along with a surcharge for poor energy efficiency performance" (International Energy Charter 2018).

In response to this, China has implemented several measures to reduce emissions levels. In the 11th Five-Year Plan for Environmental Protection (2006–2010), the State Environmental Protection Administration (SEPA) of China envisaged a stricter environmental protection plan. In the case of exports, since the mid-2000s, China implemented policies, particularly at the national-level, aimed at making export-related activities more environmentally friendly (Gourdon et al. 2015). In 2004, the Chinese government "abolished export Value Added Tax (VAT) rebates for some energy-intensive, heavily-polluting and resource-based products" (Gourdon et al. 2015, p. 7).[5] It also imposed export taxes to limit exports of goods with highly-polluting production processes and which consumed large amounts of natural resources or energy. However, up to 2011, these taxes affected mainly sulphur dioxide and chemical oxygen, although they were later extended to cover other pollutants that were released to water (Gourdon et al. 2015; Eisenbarth 2017). Also, these policies seem to have been focused on limiting exports of inputs considered strategically important and emission of heavy pollutants, while doing little to controlling carbon emissions (Eisenbarth 2017).

Despite the Chinese central government's efforts to reduce environmental pollution and degradation and to improve the efficiency of fossil fuel usage, China is one of the least efficient users of energy (International Energy Charter 2018). This might be due to absence of a will to enforce environmental laws due to the high priority given to economic growth (SEPA 2006; Liu and Diamond, 2008). For instance, Liu and Diamond (2005, p. 1181) note that 'although there has been much effort [at the national-level] to control environmental degradation, economic development often takes priority at the local-level and is still the main criterion for judging government officials' performance'. Environmental policies seem focused on conserving natural resources rather than encouraging emissions reductions (Eisenbarth 2017).

It is in this context that we examine the relationship between energy intensity and exports in China. In Sect. 3, after noting the important role of exports in emerging economy industrialization, we discuss the criticality of energy use for exporting activity.

3 Exports and energy use in emerging economies

3.1 Export-orientation of firms in emerging economies

Over the last few decades, export orientation of the manufacturing sector has played a vital role in the industrialization and catching up of several Asian economies (Amsden 1994 2001; Malerba and Nelson 2011). The literature highlights a range of firm, industry and policy related factors that have contributed to an export-led growth model in emerging economies. The most import of these factors are availability and quality of key inputs; highly connected local inter-firm networks; rapid technological upgrading;

[5] Exporters do not have to pay VAT, but firms can estimate the amount of VAT paid to domestic or foreign suppliers of raw materials, machinery, services. The abolition of these rebates meant that firms were forced to absorb the costs of VAT incurred by the production of goods for export.

product and segment specialization; and high levels of operational efficiency (Bell and Pavitt 1993; Amsden 2001; Duysters et al. 2009; Malerba and Nelson 2011; Rodrigues-Pose et al. 2013). The governments in many emerging economies also play an important role in firms' export success through policies incentivizing exports and development of crucial supporting institutions, infrastructure and other resources required to be internationally competitive (Malerba and Nelson 2011).

There is extensive evidence that exporting firms possess unique competencies in the production of more sophisticated and innovative products (Cooper and Kleinschmidt 1985; Clerides et al. 1998a, b; Christmann and Taylor 2001; Roper and Love 2002; Wagner 2007; Cassiman et al. 2010; Dosi et al. 2015). Many exporting firms upgrade their production and technological capabilities by maintaining vertical linkages with sophisticated international suppliers and consumers, and accessing their knowledge (Kim 1998; Jacob and Szirmai 2007; Salomon and Shaver 2005; Xie and Li 2018). Despite the growing interest in understanding the export performance of firms in emerging economies, there is a lack of research on the potential significance of energy use for firms' export competitiveness.

A large stream of research is focused on the association between energy-related factors and exporting at the macro- or sectoral-level. Lopez et al. (2013) and Zhao et al. (2016) employ an input–output framework and take account of countries' patterns of trade and specialization, in different stages of production. They found evidence that China's international trade has increased global emissions. Other input–output-based research points out that, compared to its exports, European Union imports from the rest of the world (including emerging economies) are characterized by larger energy and labour footprints (Simas et al. 2015). Although the low energy efficiency in emerging economies' production may appear paradoxical given the relatively high local energy prices in these countries and, particularly in China as noted earlier, firms may be able to counterbalance this by the labour-cost advantages of local production (Simas et al. 2015).

While these sector-level analyses point to a positive association between energy use and exports in emerging economies, such an outcome can occur even when the energy intensity in the production processes does not differ between firms focussing on the domestic market and those targeting foreign markets. It may be simply because of the prevailing energy-intensive production technologies in emerging countries such that greater global trade from emerging economies augments global emissions. An alternative explanation is the potential differences in energy intensities between export-oriented vs domestic-oriented production among firms (Sato 2014). Therefore, to address this puzzle and to understand whether there is any significant association between energy intensity of production operations and export orientation, a firm-level analysis is called for (Aw and Hwang 1995; Roper and Love 2002; Sato 2014). In the next sub-section, we discuss why firms' exporting may be associated with energy-intensive production, either positively or negatively.

3.2 Energy-intensive production and exporting activity in emerging economies

Engaging in exporting provides knowledge about the existence of new technologies and inputs that can improve firms' product designs and product quality, whereas firms whose production is aimed at the domestic market do not have this advantage (Salomon and Shaver 2005; Xie and Li 2018). Reliance on partners from industrialized countries, which use more advanced technologies and are subject to stricter environmental regulation, may encourage exporters in emerging economies to acquire relatively sophisticated technologies characterized by low energy and low carbon intensities. This may especially arise if the foreign clients are serving eco-conscious customers and use eco-labelling, which requires traceability of activities and environmental compliance along their value chain (Eden 2011). Firms in emerging economies may signal their commitment to environmental protection by employing relatively newer and more energy efficient technologies (Zeng and Eastin 2012). Forslid et al. (2018) study the case of Sweden (i.e., a developed country) and find a negative relationship between energy and emissions intensity and export intensity.

However, the opposite relationship can arise if products for exporting have more sophisticated and complex designs (Salomon and Shaver 2005; Srholec 2007; Xie and Li 2018), which can demand greater use of resources such as labour, time and energy, compared to products for the domestic market (Atkin et al. 2017; Simas et al. 2015). Relatedly, exporting firms' tendency to intensively use low-waged labour to achieve international competitiveness may also mean the adoption of technologies that are also highly energy intensive, as noted by previous research (Simas et al. 2015).

Furthermore, policy-makers in emerging economies face major trade-offs from unilateral improvements to environmental regulations. Given the footloose nature of global production activities and the competition among emerging economies to secure production contracts from international buyers, especially in the lower segments of the value chain (Luo et al. 2017), policy makers may be reluctant to impose regulation that makes domestic firms less competitive vis-à-vis those operating in other emerging economies. In China, in particular, energy intensity and pollution intensity in export-oriented production tends to escape policy sanction due to pressure on local officials to prioritize economic development (Simas et al. 2015; Eisenbarth 2017).

Even when firms are subject to pressure from government to improve their environmental practices, they often adopt token policies and measures that are decoupled from actual practice, with the result that government policies do not have the expected positive effects on reducing pollution and energy use (Luo et al. 2017). Similarly, adopting international environmental management standards, such as ISO14001, does not require the use of the cleanest or most energy efficient technologies; firms need only to show that they comply with national regulations (Boiral 2007).

Overall, the prevalence of labour- and energy-intensive production processes in emerging economies, combined with the generally higher level of sophistication of exported products and a rather permissive regulatory environment, might be negating the positive effects of increased consumer awareness in foreign markets and eco-labelling requirements (Managi et al. 2009). It might be that engagement in exporting by firms in emerging countries will be with energy-intensive production activities. We examine this empirically, taking into account several firm- and industry-level covariates.

4 Method

4.1 Data

We analyse a sample of firms, engaged in a range of manufacturing activities, classified as users of advanced or new technologies, located in China's Hebei province. This focus on firms located in a single region allows us to assume away major contextual differences among firms, related to the institutional and resource environment, which could influence the relationship between firm energy intensity and international competitiveness (Kafouros et al. 2015). Hebei is an important region that borders five provinces and two municipalities (Beijing, the capital of China and Tianjin, a famous trading port in north China), which has favoured the development of export activities in the province. Although Hebei is the fourth Chinese province in terms of coal production and accounts for 11% of the total, it is not among either the 10 most important electricity producing provinces or the provinces with the cheapest electricity prices (Berkeley Lab 2014).[6]

Our study uses data from a survey carried out for the Statistical report for enterprises in National high- and new-tech industrial development zone (in Hebei Province). The firms included in the survey must have been registered in mainland China for at least one year and must be the owners of the proprietary intellectual property rights to the technology used for the production of their main goods or service. They need to meet Ministry of Science and Technology of China criteria for personnel (at least 30% of employees must be college graduates, and at least 10% of employees must be engaged in R&D) and R&D expenditure (at least 3%-6%[7] of total revenue must be invested in R&D, and 60% of R&D expenditure must be incurred in China).[8] Since these firms are likely technologically more advanced than firms in a more 'representative' sample of Chinese manufacturing firms, and since energy efficiency is assumed to improve with technological sophistication, we expect to find a weaker positive association between energy intensity and exporting in our sample.

The survey was administered by the Ministry of Science and Technology of China and response is compulsory for all industrial enterprises meeting the above criteria. Thus, the survey covers all such firms in Hebei province. The survey was conducted in 2011 and the data collected refer to the previous year (1 January 2010 to 31 December 2010). It was administered to 658 firms located in Hebei province. After excluding firms with missing information for some variables and those operating in the agriculture and service sectors, we obtained a sample of 468 manufacturing firms.

[6] In 2011, the average electricity price in each province ranged from 0.36 RMB (about 3.5 GB pence) in Quinghai to 0.63 RMB (6.1 GB pence) in Guangdong, 0.54 RMB in Shanghai and 0.49 RMB (4.8 GB pence) in Hebei (Berkeley Lab 2014).

[7] 6% for revenues below RMB50 million, 4% for revenues between RMB50 million and RMB200 million, and 3% for revenues above RMB200 million.

[8] Their products or services must belong to one of the state-supported sectors (i.e., Electronic information technology; Biological and medical technology; Aviation and space technology; New materials technology; High-tech services; New energy and energy conservation technology; Resources and environmental technology; Transformation of traditional sectors through new technologies).

Despite being a selected group, the firms in our sample show considerable differences in terms of both the type of manufacturing activity and their organization. The sample covers firms from all manufacturing sectors, with relatively low representation of low technology sectors such as food, textiles, wood and rubber. The firms in our sample differ also in age (about 54% of firms are younger than 10 years), and size (20% of the sample are small firms with fewer than 100 employees, and 26% are firms with more than 500 employees). Five types of firm ownership are included: domestically owned *private firms* (64%), *state-owned firms* (18%), *collective firms* (7%), *Hong Kong-Taiwan-Macao firms* (3%) and *foreign-owned firms* (5%) (see Appendix Table 5). Thus, it can be seen that although the firms in our sample are fairly innovative, they show significant heterogeneity in several characteristics.

4.2 Econometric model and variables

We test our prediction about the association between energy use and exports using the following econometric specification:

$$\begin{aligned} Export\ intensity_i = \alpha + \beta_1 age_i + \beta_2 energy\ intensity_i + \beta_3 labour\ productivity_i + \beta_4 R\&D\ intensity_i \\ + \beta_5 human\ capital_i + \beta_6 size_i + \beta_7 state_i + \beta_8 foreign_i + \beta_9 ind.\ energy\ intensity\ growth + \vartheta_i \end{aligned} \tag{1}$$

The dependent variable is *export intensity*, defined as the ratio of the firm's total exports to its total production. It takes values between 0 and 1, including zeros and ones. Several studies use this measure to capture firm export performance (see, e.g., Rodriguez-Pose et al., 2013; Wagner, 2001).

Energy intensity is our main explanatory variable and is defined as the logarithm of the ratio of total energy used directly in the production process to total output. Energy used includes coal and crude oil and its products, natural gas and electric power. The heat values of different types of energy are measured in the same standard unit of measurement (tons of coal). Our measurement of energy intensity is in line with the conventional practice of measuring energy intensity as energy use per unit of output (Duro et al. 2010). We expect a positively significant coefficient of this variable.

The remaining variables are controls whose sign and significance are not of particular interest for our study, but which, nevertheless, may affect firm export intensity. $Productivity_i$ is labour productivity, measured as the logarithm of the ratio of total sales revenue to the total number of employees. It is a widely used measure of productivity and, compared with the popular total factor productivity, does not require unrealistic assumptions of perfect competition and constant returns to scale (Griliches and Mairesse 1984). The literature highlights a potential positive effect of productivity on firm exports, reflecting the superior efficiency and sophistication needed to compete in export markets (e.g., Clerides et al. 1998a, b; Arnold and Hussinger 2005; Atkin et al. 2017).

$R\&D\ intensity_i$ is defined as the logarithm of the ratio of total R&D expenses to total sales revenue. R&D is widely regarded as a good indicator of a firm's technological efforts (e.g., Mohnen and Hoareau 2003; Raymond et al. 2010) and, hence, may affect the firm's export competitiveness. *Human capital*$_i$ takes the value 1 if the firm has employees with a bachelor's degree or higher, and 0 otherwise (e.g., Jiang 2018). This variable reflects labour force quality, which is acknowledged to be a prerequisite for operating in competitive environments (Manova et al. 2015). *Size*$_i$ is defined as the logarithm of sales revenue (Broschak 2004). Larger size enables benefiting from economies of scale, which can provide an important advantage for emerging-economy firms that, primarily, compete on price (Nolan 1996). The last two controls are ownership: *State*$_i$ is a dummy variable that takes the value 1 for firms which are either state or collective owned and otherwise is 0; and *foreign*$_i$ is a dummy variable that takes the value 1 for firms that are foreign owned (owned by a firm outside mainland China: *Hong Kong-, Macao-firms* and *foreign-owned firms*) and 0 otherwise (Wei and Liu 2006; Chang and Xu 2008). The respective reference categories for these variables are domestically-owned private firms and domestically-owned firms. We expect that, compared with locally-owned private firms, state/collective-owned firms will be focused more on the domestic market, while foreign-owned firms are more likely to be focused on foreign markets (Liang et al. 2014). Finally, we include industry fixed effects to capture industry differences in production processes and markets.

Despite the inclusion of this wide range of controls, exogenous factors can affect the energy mix across industries (e.g., implementation of policy measures aimed at incentivising efficient energy use in certain industries or change in the growth of demand for products with different levels of energy intensity), and this potentially could affect the estimated results for the energy intensity variable. To address this potential problem, we used data from the Chinese Statistical Yearbooks to construct an industry-level variable, defined as the average growth of an industry's energy intensity over the five-year period 2006 to 2010. This variable (*industry energy-intensity growth*) proxies for changes that might affect industry-level energy use patterns and, hence, might influence firms' energy use and exports. Including this variable allows us to isolate the effect on exports of industry-level influences, such as changes to the industry production portfolio and/or industry production technologies, from firms' energy use. Since this variable represents an industry fixed effect, similar to the industry dummies, these effects are introduced separately in the models. Finally, ν_i is a composite error term [$\nu_i = \theta_i + \varepsilon_i$], consisting of industry dummies θ and the disturbance term ε_i.

Table 1 describes the variables used in our study; Table 2 presents a summary of the variables and their correlations.

The sample firms are a highly heterogeneous group in terms of export behaviour, energy use and other firm-level characteristics. Fewer than half of the sample firms are exporters (46%) and these exporting firms shows high variability in export intensity (ranging from below 1% to 85%), with the majority earning less than half of their revenue from exports. Notice, also, that, on average, exporters show three times higher energy intensity than non-exporters (7% vs 2%). However, we observe industry-wide improvements in energy use, based on the negative average growth of industry-level energy intensity. Other explanatory variables, such as firm size, productivity, ownership and capital intensity, show differences across firms, with a high

Table 1 Variables and definition

Variable	Definition
Export intensity	Ratio of total exports to total production
Energy intensity	Logarithm of ratio of total energy (tonnes of standard coal) used directly in the production process to total output (thousands yuan)
Age	Difference between the current year and the year that a firm was established
Labour productivity	Logarithm of the ratio of total sales revenue to total number of employees
R&D intensity	Logarithm of the ratio of total R&D expenses to total sales revenue
Human capital	A dummy variable which takes the value 1 if a firm has employees with a bachelor's degree or higher, and 0 otherwise
Size	Logarithm of the sales revenue
State	A dummy variable which takes the value 1 for a firm which is either state or collective owned and 0 otherwise
Foreign	A dummy variable that takes the value 1 for a firm which is foreign owned (owned by entities outside the mainland China (*Hong Kong-, Macao-firms* and *foreign-owned firms*) and 0 otherwise
Ind energy-intensity growth	The average growth of an industry's energy intensity over a five-year period from 2006 to 2010

standard deviation relative to the mean values. Finally, the correlation matrix shows no significant correlation between any pair of explanatory variables.

4.3 Estimation strategy

A fractional probit model is appropriate if the dependent variable is a proportion, as is the case with our export intensity variable (Papke and Wooldridge 1996, 2008; Wagner 2001; Ramalho et al. 2011). In fractional probit models, the dependent variable can take values between 0 and 1 and, also, can be equal to 0 or 1.[9] Since many of our firms do not export, an important question related to our choice of estimation strategy is whether there are different processes underlying export participation compared with decisions about export volumes. A pioneering paper by Wagner (2001) argues that zero export intensity represents the firm's profit maximizing decision and, thus, zeros and positive export values are governed by the same underlying process. Wagner proposed use of a one-part model to estimate export intensity (Wagner 2001). However, recent econometric research suggests that, although there may be a priori justification for using a one-part model, it is important to test the validity of its underlying assumptions (Ramalho et al. 2011; Wulff 2019). This requires comparison between a one-part and a two-part model where the participation decision and volume decisions are estimated separately.

We adopt this estimation strategy. First, we implement a one-part fractional probit model estimation of Eq. 1, in which the dependent variable, export intensity, takes both zero and non-zero values. We then compare this one-part model with a

[9] The bounded nature of the dependent variable means that a linear regression model is not appropriate.

Table 2 Descriptive statistics and correlation matrix

No	Variables	Obs	Mean	SD	Min	Max	Correlation matrix										
1	Export propensity	468	0.46	0.50	0.00	1.00	1	2	3	4	5	6	7	8	9	10	11
2	Export Intensity	468	0.09	0.17	0.00	0.85	0.56										
3	Age	468	9.92	6.06	1.00	55.00	0.16	0.03									
4	Energy intensity	468	0.05	0.43	0.00	8.83	0.05	0.04	0.01								
5	Firm Size	468	567.71	1314.89	13.00	17,473.00	0.21	0.19	0.18	-0.02							
6	Productivity	468	128.01	138.50	5.33	997.96	0.11	0.02	0	0.01	0.03						
7	R&D intensity	468	0.07	0.09	0.00	0.87	-0.22	-0.11	-0.07	0.02	-0.12	-0.21					
8	Human capital	468	0.71	0.46	0.00	1.00	0.09	0.06	0.09	0	0.09	0	0.05				
9	State/Collective	468	0.18	0.38	0.00	1.00	0.13	0.03	0.16	-0.01	0.21	0.16	-0.09	0.25			
10	Foreign	468	0.08	0.27	0.00	1.00	0.13	0.08	-0.01	-0.02	0.12	0.14	-0.11	0.12	-0.13		
11	Ind. energy-intensity growth	468	-0.12	0.03	-0.16	-0.05	-0.12	-0.07	0.04	-0.03	-0.04	-0.13	0.17	0.04	0.09	-0.1	
12	Capital intensity	468	251.13	462.92	0.38	5778.46	0.07	0.15	-0.07	0.03	0.08	0.43	-0.09	-0.03	0.03	0.16	-0.05

two-part model in which export participation is modelled using a probit model and the export volume decision is modelled employing a fractional probit model. We compare the two models, focusing on the model specifications and model fit as proposed by Wulff (2019).

In specifying a two-part model, Wulff (2019) recommends inclusion of an exclusion restriction – that is, including a variable that affects the participation decision, but not the quantity decision. We include this variable in the binary part of the two-part model to test for potential non-randomness associated with the participation decision. The export performance literature (Wagner 2001) points to the difficulty involved in finding a variable(s) able to capture the exporting decision, but not the export quantity. Some scholars argue that exporting firms have the ability to manage the entry costs associated with exporting and that this capability is unrelated to the quantity exported (Rodrigues-Pose et al. 2013). In the spirit of this suggestion and taking into account the finding that firm age is correlated with a variety of firm characteristics, such as size and productivity, we use firm age to proxy for the firm's export abilities (Klepper 2002; Arnold and Hussinger 2005). The appropriateness of this variable was confirmed empirically; we found a statistically significant effect of age on the decision to export, and absence of a significant effect of this variable on export intensity. We return to this topic in Sect. 5. We measure Age_i as the difference between the current year and the year that firm i was established.

We begin our evaluation of the one-part and two-part models by comparing the effects of the energy intensity variable in both models, following Wulff (2019). The coefficient of energy intensity is significant and positive in both the fractional regression model (beta = 0.111; p-value = 0.000) and the fractional (beta = 0.100; p-value = 0.003) and binary (beta = 0.119; p-value = 0.004) parts of the two-part model. We verified the correctness of model specification by applying the Ramsey-Reset test. The Reset test does not reject the null hypothesis that the model specification is correct for the fractional regression model (Prob > chi2 = 0. 150), the fractional part of the two-part model (Prob > chi2 = 0.193), and the binary part of the two-part model (Prob > chi2 = 0. 708).

We next compared the model fit of the two models using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) (Wulff 2019). The results indicate that, despite its complexity, the two-part model improves the fit over the fractional probit model only marginally: The AIC and BIC statistics are respectively -9.74 and -9.38 for the two-part model, compared to -9.82 and -9.65 for the one-part model. Finally, we conducted a likelihood ratio test to verify the independence of the two equations in the two-part model. This test compares a two-part model with unconstrained correlation between the errors in the two equations, with a two-part model where the correlation between the errors in the two equations is constrained to zero. The test reveals that we cannot reject the null hypothesis that the error terms in both equations are independent (Prob > chi2 = 0.461). Therefore, we can conclude that the fractional regression model enables a better trade-off between parsimony and fit, than the two-part model with exclusion restriction.

Table 3 Fractional Probit Analysis of Export Intensity

	With industry dummies		With industry energy-intensity growth	
Variables	(1)	(2)	(3)	(4)
Energy intensity		0.1108***		0.1073***
		(0.0283)		(0.0188)
Firm Size	0.2686***	0.2345***	0.2600***	0.2307***
	(0.0450)	(0.0416)	(0.0424)	(0.0424)
Productivity	-0.2320***	-0.1680**	-0.2213***	-0.1700**
	(0.0735)	(0.0753)	(0.0759)	(0.0779)
R&D intensity	0.0751*	0.0714**	0.0692	0.0716*
	(0.0402)	(0.0356)	(0.0451)	(0.0373)
Human capital	0.0844	0.1278	0.0872	0.1311
	(0.1134)	(0.1312)	(0.1117)	(0.1286)
State/Coll	-0.1223	-0.1430	-0.1363	-0.1565
	(0.1120)	(0.1135)	(0.0996)	(0.1017)
Foreign	0.0437	0.0827	0.0480	0.0703
	(0.2079)	(0.1908)	(0.1861)	(0.1678)
Industry dummies	yes	yes	no	no
Industry energy-intensity growth			-0.7837	-0.0753
			(1.1545)	(0.9955)
Constant	-2.9193***	-2.3989***	-2.9677***	-2.2762***
	(0.4122)	(0.3848)	(0.3149)	(0.3270)
Observations	468	468	468	468
Log-Psuedo likelihood	-129.5	-127.3	-130.6	-128.2
Chi-square	21.99	84.50	62.97	84.13
Significance comparison	0.233	3.07e-10	0	0

Robust standard errors, adjusted for clustering within two-digit industries, in parentheses

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

5 Results

5.1 Energy consumption and export intensity

Table 3 reports the estimates for export intensity derived from the fractional probit models. Models 1 and 2 include industry dummies. Models 3 and 4 replace industry dummies with average industry energy-intensity growth, which proxies for potential industry-level changes in energy-intensity patterns that might affect firms' energy use. Models 1 and 3 are the baseline models and include only the control variables. Models 2 and 4 also include the main explanatory variable, energy intensity. We estimate all the models with robust standard errors clustered at the industry level. While robust standard errors address problems, such as heteroskedasticity and non-normality, clustering accounts for potential correlations among observations belonging to the same industry.

The coefficient of energy intensity in production is significantly positively associated with export intensity, whether the model includes industry dummies (model 2) or average industry energy-intensity growth (model 4). In fact, the two models show no statically significant difference between the coefficients of energy intensity (chi2 = 0.12; *p*-value = 0.72). This confirms our prediction that export-oriented manufacturing activities in Chinese firms are more energy intensive than manufacturing activities aimed at the domestic market. In terms of their magnitude, a change in the log of energy intensity from the minimum value of -13.3, to the median value of -5.5, and to the maximum value of 2.2 (energy intensities of respectively 0.000002, 0.004, and 8.8) is associated with changes in export intensity respectively from 1.3%, to 8.1%, and to 27.9%.

Among the control variables, the effect of firm size is positive and significant for explaining export intensity. This is in line with the previous findings that firms with more resources and potentially greater experience are more likely to excel in international markets (Wagner 2001). The coefficient of labour productivity is negative and significant. This is a finding also noted in other emerging economy contexts (Rodrigues-Pose et al. 2013) and suggests that, in these contexts, firms may rely on more labour intensive production techniques to augment their export competitiveness.

Industry fixed effects (not reported here) are significant for explaining export intensity. However, note that average industry energy intensity growth is not significant for explaining export intensity. This suggests that industry-level changes in the patterns of energy use (caused, e.g., by targeted national energy efficiency programmes) or shifts in production portfolios (to more or less energy-intensive products) or production technologies (e.g., cleaner technologies) do not influence firm exporting behaviour.

Finally, the coefficient of R&D intensity is positive and statistically significant in the complete models, while the coefficients of state or collective ownership, foreign ownership and human capital are not significant in any of the models.

5.2 Industry heterogeneity and energy intensity of exports

Previous research suggests that the factors affecting firm export performance may vary across industries (e.g., Wagner 2001; Zheng et al. 2011). Therefore, we explore the potential effect of differences in technological and energy intensity across industries (Table 4).[10]

In the case of technology differences, since levels of product maturity and reliance on new sources and technology inputs differ significantly between low- and high-tech industries (Gereffi and Korzeniewicz 1994; Gereffi et al. 2001), the importance of energy intensity in production may also differ between these groups. We apply the OECD classification of high-tech industries, which includes pharmaceuticals, electronics, instruments and aerospace and other equipment, and class the remaining industry groups as low-tech industries (Appendix Table 6 indicates the two sets of industries) (Peneder 2003; OECD 2005). The high-tech category includes almost

[10] Inclusion of industry dummies caused convergence problems in the comparison between high-tech and low-tech industries. We therefore compared models including average growth of energy intensity in place of the industry dummies. We also compared the high-energy-intensity industry subsamples, including the industry dummies. We obtained the same results for both comparison exercises.

Table 4 Fractional Probit Analysis of Export Intensity for Industry Subsamples

	Technology class of industries		Energy intensity of industries	
Variables	(1)	(2)	(3)	(4)
	High tech	Low tech	Low	High
Energy intensity	0.1476**	0.1003***	0.1248*	0.1013***
	(0.0670)	(0.0164)	(0.0672)	(0.0185)
Firm Size	0.2624***	0.1928***	0.2065***	0.2513***
	(0.0531)	(0.0681)	(0.0682)	(0.0455)
Productivity	-0.2248***	-0.1085	-0.1023	-0.2215***
	(0.0435)	(0.1160)	(0.1031)	(0.0849)
R&D intensity	0.0640**	0.0528	0.0126	0.1406***
	(0.0260)	(0.0900)	(0.0644)	(0.0199)
Human capital	0.0379	0.1513	0.2178	0.0219
	(0.1965)	(0.1594)	(0.1523)	(0.2024)
State/Coll	-0.0473	-0.3064***	-0.0095	-0.4133**
	(0.2261)	(0.1047)	(0.1014)	(0.2019)
Foreign	0.2091	-0.0635	0.3487**	-0.2279
	(0.3253)	(0.2429)	(0.1529)	(0.2654)
Industry energy-intensity growth	1.1905	-7.1585**	0.7598	-8.4268***
	(1.6927)	(2.8253)	(1.4731)	(2.0148)
Constant	-1.9525***	-3.2257***	-2.4093***	-3.0810***
	(0.5145)	(0.5853)	(0.3851)	(0.5291)
Observations	175	293	256	212
Log-Pseudo likelihood	-49.27	-77.89	-64.50	-61.80
Chi-square	113.8	187.5	28.47	719.1
Significance comparison	0.00	0.00	0.00	0.00

Robust standard errors, adjusted for clustering within two-digit industries, in parentheses

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

40% of the firms. As expected, these firms show higher-than-average R&D intensity compared with firms in the low-tech category (8.7% vs 6.5%) and, also, have slightly higher export intensity (9.6% vs 8%) and substantially lower energy intensity (1.4% vs 6.4%).

The econometric results indicate that the coefficient of energy intensity is positive and significant in both the low-tech and high-tech samples and their effects are not statistically different (Chi2 = 0.51; p-value = 0.47). The finding of a significant export intensity coefficient for the high-tech sample, although perhaps surprising, is in line with our earlier discussion on the specificities of exporting activities in emerging economies. Since export products tend to be relatively more sophisticated than goods produced for the domestic market, their production is likely to require more resources, especially if the exporter, although part of the high-tech sector, employs technologically less complex and more resource-intensive production processes.

Next, we conducted a separate analysis for low and high energy-intensive industries, defined based on industry-level data obtained from Chinese Statistical Yearbooks. We identified high energy-intensive and low energy-intensive industries using the median cut-off for industry average energy intensity (Appendix Table 6 lists the two sets of industries; Appendix Table 7 reports industry average export intensity). More than half of the firms (54%) are active in low energy-intensive sectors, with average energy intensity of 1% compared to the 8.8% average for high-energy intensive industries. Firms in high energy-intensive industries show slightly higher export intensity (9.6%) compared to firms in low energy-intensive industries (7.7%). However, the former group spends less on R&D (6% vs 8.5%). We find that, in line with these results, the coefficient of energy intensity is weakly significant in low energy-intensive industries (10% level) and is highly significant (1%) in the case of high energy-intensive industries.

5.3 Robustness checks

While we have argued and our tests have confirmed that the decision to participate in export activities and the decision about export volume are governed by the same process, we checked whether energy intensity has a different effect on these two decisions. As described above, we estimated a two-part model consisting of a binary part for the export participation decision and a fractional part for the export quantity decision. The binary part of the model included an exclusion restriction, age, which is correlated with the export decision, but not the decision about the quantity exported. Our analysis revealed a statistically significant association between energy intensity and both the decision to export and the export intensity (respectively beta = 0.119; *p*-value = 0.004 & beta = 0.100; *p*-value = 0.003). A Wald test reveals that these coefficients are not statistically different (chi2 = 0.16; Prob > chi2 = 0.692). We can conclude that the role of energy intensity is similar in the decision to export and the decision about export volume.

There might be concern over endogeneity of the energy intensity variable biasing our results. This could occur if the energy intensity variable is correlated with the error term, which may happen because of potential omitted variables that may cause an overestimation of the coefficient of energy intensity. To rule out this possibility we performed the following tests.[11] First, we employed a two-stage estimator (using the Stata 'cmp' package) of export intensity and energy intensity with the latter equation including an additional predictor. The Fisher z-transformation correlation between the two equations was not statistically significant (*p*-value = 0.118), suggesting the absence of endogeneity. The additional predictor (the instrumental variable) in the energy intensity equation is *Capital intensity*, defined as the logarithm of the ratio of the firm's total fixed assets to the firm's total number of employees—the capital-labour ratio.

[11] Note that because the focus of this paper is on the association between energy intensity and exporting and the use of cross-section data does not permit examining lagged effect, the tests we describe are aimed at establishing the correlation between energy intensity and export intensity, not the potential causal effect of the former on the latter.

The condition for being a good instrument is that it is correlated with the endogenous variable but not correlated with the dependent variable except through the endogenous variable (Cameron and Trivedi 2005). The capital-labour ratio captures the resource bias in production techniques such that we can expect a positive association between the two (Simas et al. 2015), especially if capital includes older vintages, as demonstrated by a recent sector-level study on China (Wu et al. 2012). Thus, capital-labour ratio is likely to be correlated with exporting, but only indirectly.

Second, to test the validity of the instrument, capital intensity, we employed a two-stage least squares estimator, using Stata's ivregress command.[12] We then performed the Stock and Yogo (2005) test for weak instruments (Stock et al. 2002); the test statistic (29.79) exceeded the critical value (16.38) at the 5% level, allowing us to reject the null hypothesis of a weak instrumental variable. The estimated coefficient for the energy intensity variable, correcting for potential endogeneity is still significant at the 5% level (p-value = 0.024).

Overall, these results point to a significant association between energy intensity and export intensity.

6 Discussion and Conclusion

The rapid industrialization of numerous emerging economies, based on the adoption of an export-led growth strategy, is increasing concern about the deleterious consequences for the environment. The aim of this paper was to add to our understanding of whether or not firms' energy-use behaviour differs in relation to production for domestic and export markets. We considered several factors that potentially might affect exporting.

Our research context is the highly export-oriented emerging economy of China; our data, which are derived from a survey, include 468 firms. The analysis reveals that firms' energy-use intensity is positively associated with exporting activity. In other words, the manufacturing activities of firms that export most of their output tend to consume more energy per unit of output, than the activities of firms that sell most of their output in the domestic market. Even in the case of our sample firms that can be considered technologically sophisticated, those oriented more to exports are linked to more energy- and pollution-intensive techniques. This relationship holds across industries with different technological characteristics (low-tech vs high-tech) and is particularly salient in industries characterized by high levels of energy-use intensity.

An important implication of our findings is that the well-documented meso and macro positive relationship between emerging economies' exports and emissions may reflect the presence of different techniques for export-oriented vs domestic-oriented production. Such an outcome may point to several unique pressures that exporting firms are subject to compared with firms focusing on the domestic market. One of these might be that the goods produced for foreign markets are relatively more sophisticated and complex than those aimed at the domestic market, with the result that

[12] The two-stage model we adopted requires the continuous dependent variables; we therefore logit transformed the export intensity variable (Baum 2008; Beverelli et al. 2015; Saenz and Thompson 2017).

production for export could take more time, labour and energy inputs, especially when combined with resource-intensive technologies prevalent in emerging economies (Salomon and Shaver 2005; Atkin et al. 2017; Simas et al. 2015; Xie and Li 2018).

Yet another, complementary, explanation might be the relatively permissive environmental policies in emerging economies compared to advanced export markets. Inherently more energy- and pollution-intensive processes will be more costly if performed in countries with stringent environmental regulations, with the result that exports from emerging economies may be biased towards more energy-intensive products. Also, in emerging economies where export-oriented economic growth is a government priority, firms producing primarily for domestic markets may receive limited local regulatory leniency in relation to emissions, when compared with those producing primarily for foreign markets (Eisenbarth 2017). More research using qualitative methods might provide a better understanding of the mechanisms underlying the relationship between exports and energy use in emerging economies.

From a policy perspective, given that exporting is one of the main drivers of overall growth in China, our findings raise concerns about China's ability to reduce its pollution. China's central government has attempted to limit pollution-intensive production for export through the imposition of taxes (Gourdon et al. 2015). However, regional-level policies, such as the stricter environmental regulations and working conditions imposed by the Guangdong regional government, have led to the closure of many exporting firms (Sharif and Huang 2012). Despite these efforts, our results show that, on average, export-oriented production activities are more energy-intensive than domestic-oriented activities. Unlike in industrialized countries, where more stringent environmental standards have been shown to drive innovation and exports (Costantini and Crespi 2008; Costantini and Mazzanti 2012; Forslid et al. 2018), in emerging economies like China, institutional and technological capabilities appear insufficient to ensure the potentially win–win effects of environmental regulation.

An environmentally-sustainable export-oriented path to development in emerging economies calls for better international coordination and cooperation to enable technology transfer and appropriate environmental regulation (Humphreys, 1996; Brandi et al., 2020). This should involve cooperation related to the development and diffusion of clean technologies and the harmonization of climate- and sustainability-related policies, between the industrialized and emerging economies. Such international coordination should include both countries and Multinational Corporations (MNCs), without whose commitment, the policies implemented will fail. Currently, MNCs seem able to engage in international arbitrage, thereby circumventing resource costs and stringent environmental regulation in industrialized countries (Fung et al. 2011) while emerging-economy firms tend to respond symbolically to policies and regulatory pressure (Luo et al. 2017). MNCs can play a more proactive role. MNCs should refine the designs of relatively complex and sophisticated products that involve energy-intensive production processes and support emerging country firms to adopt newer, less energy-consuming technologies and processes (Ning and Wang 2018). National governments in both the developed and the emerging economies should coordinate with MNCs for the establishment of bilateral and multilateral trade agreements that include feasible but still ambitious environmental provisions (Brandi et al. 2020).

This study contributes to the literature on emerging economy firm exporting, which stresses the technological and organizational differences between exporters and non exporters (Clerides et al. 1998a, b; Roper and Love 2002; Salomon and Shaver 2005; Wagner 2007). This study demonstrates the different environmental impact of the production processes in firms with different levels of involvement in exporting. We also contribute to the much-contested debate in this literature on whether the decision to export and the decision about how much to export follow a similar process or not. In line with the argument of Wagner (2001) that these two decisions follow the same process, our tests recommend adopting a one-part model where exporting is modelled using a single equation, with the dependent variable, export intensity, taking both zero and positive values.

The findings of our study contribute, also, to the international trade literature, which shows the increasing involvement of global value chains and suggests that "export competitiveness is inextricably linked to having access to competitively priced intermediate imports" (Kowalski et al. 2015, p. 11). In particular, our finding that export intensity is associated with the energy intensity of production activities suggests that this might influence decisions concerning the choice of suppliers and location of production activities. These decisions may depend on differences across countries not only in technological competences and resource and/or labour abundance, as is generally understood, but also in the possibility to carry out energy-intensive production activities (Forslid et al. 2018). Our data, however, did not permit distinguishing exporting firms based on their involvement in the global value chain. Future studies may explore this important research avenue.

Finally, the environmental economics literature suggests that the choice to use energy-intensive production techniques by developing countries might result from the type of the firm's technological and organizational resources and weak environmental regulation and environmental awareness among their populations (Stern 2004; Levinson and Taylor 2008; Zhao et al. 2016). Our results suggest that the energy-use behaviour of firms in emerging economies may be influenced, also, by foreign demand. This suggest that persuading exporting firms in emerging economies, such as China, to abandon energy intensive manufacturing activities might be a formidable challenge.

This study has some limitations which suggest directions for future research. First, our sample consists of firms with potentially higher technological capabilities compared to the average Chinese firm. Since we expect our sample firms to use more advanced and less polluting production technologies, our finding of a positive association between energy intensity and exports suggests that this relationship is likely to hold for a more representative sample of firms. Future research could investigate this relationship using a more representative sample of firms, in other Chinese regions for which data, in particular panel data, are available. Future research also could examine the extent to which our specific findings could be generalized to other emerging economy contexts, bearing in mind that institutions and firms' international orientation and resource endowments vary significantly across countries.

Second, we controlled for different firm characteristics, including sector of activity, but are unable to identify the product family or value chain segment occupied by our sample firms. Future research could focus on manufacturing activities across product families to provide insights into differences in the characteristics of the goods produced for export and for the domestic market, and differences in the production processes underlying the same product family in multiple global locations.

Third, our data do not allow us to identify the location of foreign buyers. Future research could examine whether the types of goods exported to other emerging economies differ from the types of goods exported to advanced countries with stricter environmental regulations, and whether these importers are domestic firms or affiliates of multinationals. This would permit a more accurate understanding of the specific type of incentives for energy-intensive production.

Fourth, our static analysis does not allow insights into how Chinese exporters might respond to changes in China's environmental standards or the environmental standards in other countries. Future research could use simulation techniques to explore the elasticity of energy intensive exports from China in the context of a shift towards more stringent environmental standards in China or/and abroad. This would be informative for policy makers in China and other emerging economies, in relation to pollution and trade policies.

Finally, we considered the energy intensity of production activities, which proxies for environmental degradation, but were not able to disentangle energy sources and, in particular, the extent of use of renewable energy. We also did not consider other sources of environmental degradation, such as hazardous inputs, not necessarily linked to use of energy in production. Incorporating these fine details of production processes could provide a better understanding of the interconnectedness between environmental policies, trade and pollution.

Appendix 1

Table 5 Summary of ownership categories in the sample

Ownership	Freq	Percent	Cum
State-owned enterprises	82	17.52	17.52
Collective enterprises	33	7.05	24.57
Private enterprises	298	63.68	88.25
Hong Kong-Taiwan-Macao enterprises	12	2.56	90.81
Foreign enterprises	22	4.7	95.51
Others	21	4.49	100
Total	468	100	100

Appendix 2

Table 6 Summary of industry categories in the sample

Sample Industry Classification	Two-digit industries	Number of Firms	Tech class	Energy intensity
1	C13_Processing of agricultural and sideline products	3	low	low
2	C14_food manufacuturing	5	low	high
3	C17_textile manufacturing	7	low	high
	C18_Manufacture of Textile Wearing Apparel, Footware and Caps			
	C19_Manufacture of Leather, Fur, Feather and Related Products			
4	C20_Processing of Timber, Manufacture of Wood, Bamboo, Rattan,Palm and Straw Products	7	low	high
	C22_facture of Paper and Paper Products			
	C23_Printing,Reproduction of Recording Media			
5	C25_Processing of Petroleum, Coking, Processing of Nuclear Fuel	55	low	high
	C26_Manufacture of Raw Chemical Materials and Chemical Products			
	C28_Chemical Fibers manufacturing			
6	C27_Medical and pharmaceutical products	52	high	high
7	C29_Rubber and Plastics products	19	low	high
8	C30_Manufacture of Non-metallic Mineral Products	20	low	high
9	C31_Smelting and Pressing of Ferrous Metals	40	low	high
	C32_Smelting and Pressing of Non-ferrous Metals			
	C33_ Manufacture of Metal Products			
10	C34_Manufacture of General Purpose Machinery	31	low	low
11	C35_Manufacture of Special Purpose Machinery	78	low	low
12	C36_Manufacture of Automobiles	30	low	low

Table 6 (continued)

Sample Industry Classification	Two-digit industries	Number of Firms	Tech class	Energy intensity
	C37_Manufacture of Railway, Ship, Aerospace and Other Transport			
13	C38_Manufacture of Electrical Machinery and Apparatus	43	high	low
14	C39_Manufacture of Computers, Communication and Other Electronic Equipment	51	high	low
15	C40_Manufacture of Measuring Instruments and Machinery	20	high	low
16	C41_Other Manufacture	7	low	high
Total		468		

Appendix 3

Table 7 Sectoral pattern of energy consumption, export and revenue in China, 2005–2013

Code	Industrial category	Energy consumption (10,000 tons of SCE)	Export (100 mill yuan)	Revenue from principal business (100 mill yuan)	% of all sectors		
					Energy consumption	Export	Revenue from principal business
	Total Economy	2,827,117.33	940,031.64	5,472,310.33	100%	100%	100%
C13	Processing of agricultural and sideline products	24,317.38	8785.41	280,458.73	0.86%	0.93%	5.13%
C14 + 15 + 16	Food manufacturing; Manufacture of Liquor, Beverages and Refined Tea; Manufacture of Tobacco	26,088.93	12,346.84	210,592.38	0.92%	1.31%	3.85%
C17 + 18 + 19	Textile manufacturing; Manufacture of Textile Wearing Apparel, Footwear and Caps; Manufacture of Leather, Fur, Feather and Related Products	67,624.60	161,257.72	379,177.46	2.39%	17.15%	6.93%
C20	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	9263.29	7237.36	56,173.83	0.33%	0.77%	1.03%
C22	Manufacture of Paper and Paper Products	34,173.25	7580.83	78,387.39	1.21%	0.81%	1.43%

Table 7 (continued)

Code	Industrial category	Energy consumption (10,000 tons of SCE)	Export (100 mill yuan)	Revenue from principal business (100 mill yuan)	% of all sectors		
					Energy consumption	Export	Revenue from principal business
C26	Manufacture of Raw Chemical Materials and Chemical Products	282,655.85	42,909.84	381,750.71	10.00%	4.56%	6.98%
C29	Rubber and Plastics products	30,279.73	31,411.98	149,684.35	1.07%	3.34%	2.74%
C31 + C32	Smelting and Pressing of Ferrous Metals; Smelting and Pressing of Non-ferrous Metals	602,539.97	73,413.64	668,434.74	21.31%	7.81%	12.21%
C34 + C35 + C38	Manufacture of General Purpose Machinery; Manufacture of Special Purpose Machinery; Manufacture of Electrical Machinery and Apparatus	59,734.00	403,715.91	731,208.65	2.11%	42.95%	13.36%
C36 + C37	Manufacture of transport equipment	42,345.38	46,534.17	409,108.57	1.50%	4.95%	7.48%

Data source: National Bureau of Statistics of China, Chinese Statistical Yearbooks (CSY), various issues between 2007 and 2014

1) The values of Energy consumption, Export and Revenue from principal business were summed based on the yearly data between 2005 and 2013. 2) Revenue from principal business covers only the industrial enterprises above designated size (with revenue from principal business above 5 million yuan before 2011, and above 20 million yuan since 2011). 3)Due to the fact that coverage of Export section in CSY is different from that of energy consumption and revenue sections, here we report only 12 matching categories

Data availability The dataset used in the current study is not publicly available. It derives from a survey administered by the Ministry of Science and Technology of China. The authors obtained the data and the permission to use it because of the involvement of the fourth author of this paper in the administration of the survey.

Declarations

Conflicts of interest The authors declare that they have no conflicts of interest or funding to report.

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