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Environmental regulation and intermediate imports: Firm-product-level evidence[☆]

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ABSTRACT

This study examines the effects of domestic environmental regulations on import activity. Using a panel of firm-product-level data and variations in regulatory stringency across products established by China's Eleventh Five-Year Plan for Environmental Protection (covering 2006–2010), it reveals that tougher regulations on emission-intensive industries at home led to increases in downstream manufacturers' imports of emission-intensive intermediate inputs. Specifically, a 1% increase in sulfur dioxide emission intensity resulted in a 0.026% increase in intermediate imports after the implementation of the regulation. A back-of-the-envelope calculation suggests that, although the regulation increased emissions in source countries, it reduced global emissions of sulfur oxides and carbon dioxide. This is because the increases in imports caused by the regulation mainly came from countries with lower emission intensity than China. The regulation did not disproportionately increase imports from or emissions in developing countries.

1. Introduction

The growing body of literature on trade and the environment provides ample evidence for the pollution haven effect (see, for example, Levinson and Taylor, 2008). Empirical studies find that new environmental regulation within a country can lead to a reduction in its exports or to a rise in net imports. However, the question of whether it also increases imports directly has received little attention. This knowledge gap hinders our understanding of the impacts of environmental regulation on trade flows between countries and the global distribution of emissions. To address this, our study examines whether stricter regulations within a country affect its imports of emission-intensive intermediate goods. We analyze a large dataset in detail and provide the first firm-product-level evidence from China.[1]

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[1] Product here refers to intermediate input imported, but not product manufactured by the firm itself. The WTO statistics show that trade in intermediates accounts for 47% of global trade at the end of the fourth quarter in 2022.

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China serves as an ideal context for our exploration for two key reasons. First, the country has experienced rapid growth in intermediate imports over the past few decades. Second, there has been a temporal and industry-level (and product-level) variation in regulatory stringency within the country, allowing us to identify the effects on intermediate imports. Through the Eleventh Five-Year Plan (hereafter, the Eleventh FYP) for Environmental Protection (covering 2006–2010), China strengthened its air quality regulations to reduce emissions of sulfur dioxide (SO_2) (Cao et al., 2009; Karplus et al., 2021).[2] The regulations restrained the economic activities of regulated industries (Shi and Xu, 2018). It may increase the production cost that could be passed through to downstream industries. Consequently, downstream firms can opt for substitutes for domestic intermediate inputs.

This paper analyzes whether stricter domestic environmental regulations, as established by the Eleventh FYP, led to increased imports of emission-intensive intermediate inputs by Chinese downstream manufacturers. Our measure of regulatory stringency is based on the SO_2 emission intensity of an intermediate if it were manufactured domestically. The rationale is that the higher the intensity, the more stringent the regulation. We then estimate difference-in-differences models and find strong evidence suggesting that stricter regulation on an emission-intensive intermediate good at home leads to more imports of the good by downstream firms. Moreover, the effect is more pronounced for intermediates with higher emission intensities. Specifically, a 1% increase in emission intensity of an intermediate would lead to a 0.026% increase in the imports of the intermediate after the implementation of the regulation. While the regulation increased emissions of sulfur oxides (SO_x)[3] and carbon dioxide (CO_2) in the source countries, it ultimately reduced global emissions. This reduction occurred because the increased imports triggered by the regulation originated primarily from countries with lower emission intensity levels than China.

In our analysis, we address several identification threats. Specifically, we examine possible confounding factors, including changes in demand shocks from importers' downstream industries, input composition, and other shocks from domestic and international markets. We also investigate potential confounding policies for trade, the environment, and energy. Our baseline estimates are robust to these checks. In addition, we examine the channels through which the regulation affected intermediate imports. The results indicate that the regulation induced existing importers to import more of the emission-intensive intermediates. It also created incentives for non-importers to enter the import market. Notably, these effects were more pronounced for intermediates with higher emission intensities.

Our paper is related to three lines of literature. First, it contributes to the literature on trade and the environment by providing new firm-product-level evidence regarding the effect of environmental regulation on imports. Existing studies have focused mainly on exports (Cherniwchan and Najjar, 2022; Hering and Poncet, 2014; Shi and Xu, 2018), net exports (Levinson and Taylor, 2008), and foreign direct investment inward or outward (Cai et al., 2016; Hanna, 2010). Some previous studies have also documented that tighter regulations increase imports of energy- or emission-intensive inputs (Aldy and Pizer, 2015; Ederington and Minier, 2003; Sato and Dechezleprêtre, 2015). However, to our knowledge, these import studies have primarily relied on industry-level data and regulations in developed countries (Ederington et al., 2005). In contrast, our paper presents new evidence at the firm-product level from a large developing economy. The data allow us to account for both firm- and product-level determinants of imports. Despite this methodological difference, our main findings align with prior research that used more aggregated data. Additionally, we utilize the rich information in the dataset to explore the channels through which stricter regulation affected firm imports.

Second, our study contributes to the broader literature on the impacts of environmental regulation on economic activities. Numerous studies have estimated the control costs of environmental policies on firms or industries that are directly targeted. Most of these studies find negative impacts (Curtis, 2018; Greenstone, 2002; List et al., 2003; Sheriff et al., 2019; Walker, 2013) or insignificant effects (Berman and Bui, 2001; Martin et al., 2014) on employment, investment, and shipment in the United States, Europe, and other countries. Studies on China have found that stricter regulations reduced employment (Liu et al., 2021), hindered capital flows (Cai et al., 2016; Chen et al., 2018), and decreased production (He et al., 2020). Our paper differentiates itself from previous studies by focusing on downstream firms' decisions to source intermediate inputs from emitting industries targeted by the regulations. Therefore, the estimates are also relevant for discussing the distributional impacts of environmental policies (Fullerton and Muehlegger, 2019).

Lastly, our paper adds to the literature on China's increasing engagement in the global economy. Our results reveal that environmental regulation is a determinant of firms' decisions on intermediate imports. The current literature provides evidence on the impacts of imported inputs on firm performance, such as competitiveness (Dechezleprêtre and Sato, 2017), productivity (Halpern et al., 2015), labor markets (Hummels et al., 2014), but few on why firms conduct offshoring. Exceptions include studies by Kee and Tang (2016) and Li and Zhou (2017). Notably, much of the existing research focuses on developed countries such as the United States (Choi et al., 2023) and Japan (Cole et al., 2014), with limited attention to developing economies. In our paper, we provide empirical evidence that unilateral environmental regulation (a behind-the-border policy) within China influences firm's sourcing decisions for intermediate inputs. This finding contributes to the empirical literature on the determinants of global value chain participation (Antràs and Chor, 2022; Johnson, 2018).

The remainder of this paper proceeds as follows. Section 2 provides background information on the regulation. Section 3 describes the data sources and some facts. Section 4 presents the empirical strategy. Section 5 summarizes the main empirical results. Section 6 discusses findings from further analyses. Section 7 concludes.

[2] The government plan explicitly sets goals for reducing SO_2. Another key pollutant is the chemical oxygen demand, which is an indicator of the assessment of water quality. In this paper, we focus on domestic SO_2 regulation.

[3] For examining the environmental implications of the regulation at global scale, we focus on SO_x, but not on SO_2. The reason is that we do not have sufficient data on country-product-level (or country-industry-level) SO_2 intensity. However, as described later in the paper, the WIOD data allow us to calculate SO_x intensity.

2. Background of the regulation

China has established a comprehensive environmental regulatory system, with successive *Five-Year Plans for National Economic and Social Development* (FYPs) playing a crucial role (OECD, 2007). Through these plans, the central government sets the agenda and priorities for public policies, including environmental progress over specific time periods (Karplus et al., 2021). Under the umbrella of the FYP, environmental authorities formulate the *Five-Year Plan for Environmental Protection* (FYPEP). The central government published the first standalone FYPEP for the seventh FYP period (covering 1986–1990). However, the preceding regulations outlined in the FYPEPs were often lax or poorly enforced (Van Rooij, 2006).

Since the early 2000s, environmental quality in the country has gained significant attention both domestically and internationally. To strengthen regulation and improve compliance, for the first time, the Eleventh FYP (covering 2006–2010) incorporated environmental protection as a criterion in the performance evaluation of local leaders. Consequently, the likelihood of government leaders being promoted now partially depends on environmental quality in their respective areas of responsibility (Xu, 2011).[4] This change has encouraged local governments and leaders to attach greater importance to the environmental impacts of their actions (Wang, 2013).

In the Eleventh FYP, the central government set a target of reducing SO_2 emissions by 10% nationwide. To achieve the objective, the FYPEP for the period made a highly comprehensive plan that described strategies and specific policy instruments. It also introduced revisions and additions to existing air quality regulations, such as the Two Control Zones policy aimed at reducing SO_2 emissions in specific regions (Hering and Poncet, 2014). Local officials relied on various regulatory measures that include requiring investments in mitigation capability (e.g., SO_2 scrubbers), shutting down small polluting or energy-consuming plants (e.g., smelters), and intensive monitoring and stricter enforcement (e.g., effluent emission standards). By the end of the five-year period, China had met the target, with SO_2 emissions decreasing by 14.3% in 2010 compared to the 2005 level. Most major emitting manufacturing industries were able to meet or exceed the reduction goals set by the regulation. Existing studies confirm that the Eleventh FYP on environmental protection significantly impacted firm behavior and aggregate economic outcomes (see, e.g., Shi and Xu, 2018).

3. Data and motivating facts

3.1. Data sources and key variables

We primarily draw our data from four sources that have been widely utilized in various literatures. The first source is China's General Administration of Customs, which provides product-level trade transaction data on both imports and exports. The database covers all Chinese imports and exports, and our study uses information on imports from 2001–2010. For each import transaction, it includes rich information at the 8-digit level of the Harmonized System (HS) product classification, including physical quantity, monetary value, source country and contact details of the importing firm (such as name, telephone number, zip code, and contact person). We aggregate the HS 8-digit level to the HS 6-digit level to match other data (such as import tariff rates). In addition, the database reports the trade mode (normal or processing).[5] However, it lacks other relevant information, such as the firm's balance sheet.

The second data source is the Annual Surveys of Industrial Firms (hereafter ASIF), which are conducted by China's National Bureau of Statistics. The surveys cover all state-owned firms and all non-state-owned firms with annual sales exceeding 5 million RMB (about 0.8 million US dollars). The ASIF records rich firm-level information, including firm's county of location, industry, birth year, ownership, employment, and output value. Each firm in the ASIF has a unique ID (that is, a legal entity code).

To obtain the necessary firm-level information for importers, we merge the trade data and the ASIF. However, the firm ID in the ASIF differs from the importer ID in the trade data. To address it, following Yu (2015), we match the two datasets using the firm name. When the names of a firm from the two samples are exactly the same, the matching is completed directly. For the remaining unmatched observations, we use other information, such as the firm's phone number and postal code to match the observations of the two datasets.[6] In addition, we extract core elements from the firm's name and combine them with the firm's address information for further matching. Following Brandt et al. (2012), we remove outliers and clean the combined trade-ASIF data. In particular, for later firm-level analysis, we exclude observations with negative or zero values for value added or output. We also drop firms with fewer than eight workers, as these small firms are in a different legal regime. Additionally, we exclude observations falling in the 0.5% upper or lower tails of key variables (i.e., value of imported intermediates, firm's output value, real capital stock, and the ratio of capital stock to the number of employees).

The third source of data is the Environmental Survey and Reporting (ESR) program, administered by China's Ministry of Environmental Protection (formerly known as the State Environmental Protection Administration). The ESR data include information on a polluter's name, ID and emissions of different pollutants, including SO_2.[7]

To measure the stringency of regulations for emitting industries (and the products), we need to calculate the emission intensity for each HS 6-digit product in China (i.e., SO_2 emissions per unit of output value) in 2005 (one year before the regulation was initiated).

4 Previously, promotion chances were largely tied to local economic growth (Li and Zhou, 2005).

5 For further context, refer to detailed descriptions provided by Brandt et al. (2017) and Yu (2015).

6 This approach is useful because phone number and postal code are unique within an area.

7 For more information about the ESR, refer to Wang et al. (2018), which also provide details on how to merge the ASIF and ESR data.

It proceeds in three steps. First, we merge the ASIF and ESR data for the year 2005. Second, we aggregate the merged firm-level data to the 4-digit Chinese Industry Classification (CIC) industry level, allowing us to obtain total emissions and total output value (and subsequently the emission intensity) for each industry. We exclude two CIC 4-digit industries where the calculated emission intensity is obviously anomalous due to the very small number of firms or the presence of outliers.[8] Finally, we link the HS 6-digit products to their respective CIC 4-digit industries. In most cases, each product corresponds to one specific industry. We set the emission intensity of the product equal to the emission intensity of the industry. In exceptional cases where one HS 6-digit product spans multiple CIC 4-digit industries,[9] following Nunn (2007) and O'Mahony and Timmer (2009), we define the emission intensity as the arithmetic mean of the corresponding CIC 4-digit industries' intensities. Then we are able to match the emission intensity of each product and trade transaction data by the HS 6-digit code.

The fourth source of data is the World Input–Output Database (WIOD) and its associated socioeconomic accounts, which are based on official and publicly available data from statistical agencies (Timmer et al., 2015). It covers 28 EU countries and 15 other major economies for the period from 2000 to 2014, plus an economy called "ROW". Due to the lack of emission data for Switzerland, Croatia, and Norway, we include these three countries in the "ROW". Note that the emission data cover the period from 1995 to 2009. For a number of purposes in this paper, we need country-industry-level emission intensity. To calculate it, we use the ISIC concordance table to map the output value to the WIOD-35 level, consistent with the emission data.

In addition to the four sources above, we also use data from official publications such as the *China Statistical Yearbook*. It allows us to calculate the output price index,[10] which is used to deflate firm-level variables such as output value and capital stock. Following Kee and Tang (2016), we also construct an industry-specific[11] time-varying import price index based on firm-level imports from the trade transaction data. All monetary variables are deflated using 2001 as the base year.

3.2. Trends in intermediate imports

Before formally assessing the impact of the regulation on intermediate imports, we briefly explore the trends in intermediate imports and SO_2 emission intensity over the years.

Perhaps the most obvious fact that indicates the importance of intermediate imports by China is that its share in total imports stayed high over the years. The solid line in Fig. 1 depicts the share throughout the period from 2001 to 2010. It indicates that during this period, except for 2001, the share remained roughly stable within the range of 70% to 75%. The total value of intermediate imports grew from approximately 149 billion US dollars in 2001 to 584 billion US dollars in 2010. The significant increase after 2001 may be related to China's accession to the WTO. As for the (value-weighted) mean SO_2 intensity of imported intermediates,[12] it experienced significant declines in the years before 2005. However, after 2006, when the government began implementing the Eleventh FYP, the declining trend seemed to end, followed by a slight increase. The dashed line in Fig. 1 shows the intensity over the years.

In summary, the message of Fig. 1 is clear. Despite maintaining a stable and high share of intermediate imports in total imports over the years, the trend of falling mean SO_2 emission intensity ceased after 2006, coinciding with the implementation of the Eleventh FYP.

To gain further insights into the trend in mean intensity, we classify intermediates into two groups: low-intensity and high-intensity, based on their emission intensity. In the left panel of Fig. 2, the line shows the share of imports of low-intensity intermediates, defined as those with emission intensity at or below the 25th quantile. The shaded area above the line corresponds to the share of high-intensity intermediates. It clearly indicates that the share for the low-intensity intermediates was continuously increasing before 2006, followed by a significant decrease. In contrast, the share for the high-intensity intermediates increased after 2006.

The subsequent panels in the figure use different criteria for classifying high- and low-intensity intermediates. Remarkably, we observe similar trends: the Eleventh FYP has significantly altered China's patterns of intermediate imports, shifting from importing more intermediates with low emission intensity to importing more intermediates with higher emission intensity.

[8] The two industries are the "Mining and processing of Aluminum" (CIC 4-digit industry code: 0916) and the "Other precious metal smelting" (CIC 4-digit industry code: 3329) industries. Each of these industries had fewer than ten firms in the ESR in 2005, and both contain observations where zero values are reported for emissions or output value.

[9] For example, product "glucose and glucose syrup" (HS 6-digit code: 170230) exists in both industry "manufacturing of starch and starch products" (CIC 4-digit industry code: 1391) and industry "manufacturing of chemical raw drugs" (CIC 4-digit industry code: 2710).

[10] Since Brandt et al. (2017) only provides the output price index for 1998–2007, we use related information to calculate the output price index for 2008–2010.

[11] The industry-specific here refers to the 21 industry categories formulated by the United Nations based on the international HS codes. Each category corresponds to multiple HS 2-digit codes.

[12] The mean SO_2 emission intensity is defined as the ratio between the sum of the emissions of imported intermediates if they were produced in China divided by the sum of the import values of the intermediates. Specifically, we multiply the import value of an intermediate by its emission intensity in 2005 to obtain the emissions. See Section 3.1 for more information on how to calculate product-level emission intensity.

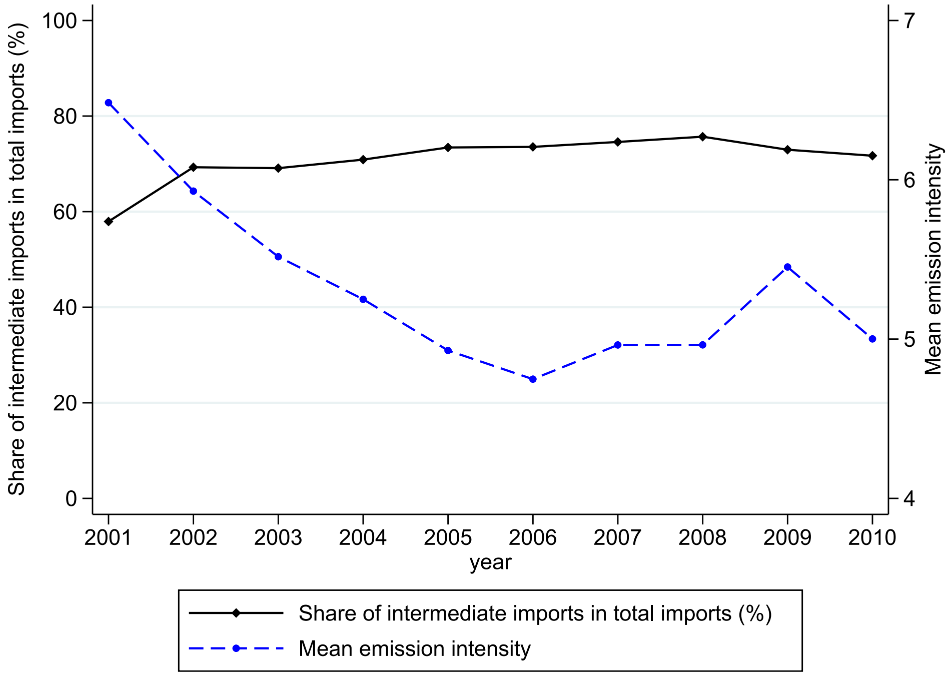

Fig. 1. Intermediate imports: Share in total imports and mean emission intensity.
Notes: The solid line displays the dynamic trajectory of the China's proportion of intermediate imports relative to the country's total import value from 2001 to 2010. The dashed line shows the trend of annual average SO_2 emission intensity associated with imported intermediates in China. The intensity is calculated by multiplying the import value of intermediate goods by their emission intensity, aggregating these obtained numbers by year, and then dividing by the total import value in that year. The import value is deflated using the import price index, with 2001 as the base year. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

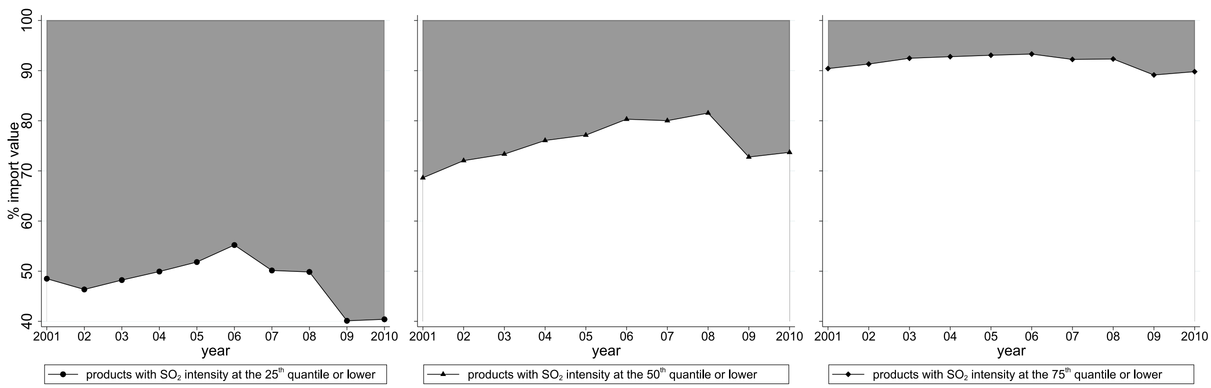

Fig. 2. Share of imports of intermediates with low emission intensity.
Notes: The lines depict the share of imports of intermediates with low emission intensity. The left panel defines the low-intensity group as those products with emission intensity at or below the 25th quantile. The central and right panels use the 50th and 75th quantiles, respectively.

3.3. Environmental effects of importing the intermediate inputs

Although the figures presented above provide insights into the dynamics of China's intermediate imports and the differing trends between low-intensity and high-intensity intermediates, they do not speak much about the environmental effects of intermediate imports over the years. In this section, we calculate these effects by focusing on two pollutants: SO_x and CO_2. We consider CO_2 because it is global in nature and a co-pollutant of sulfur oxides in many industries.

There are at least two possible approaches to calculate environmental effects: a simple, naive, and direct computation and another that relies on the input–output framework (e.g. Levinson, 2009). We choose the direct approach that employs the trade transaction

Table 1
Environmental effects of China's imports of intermediate inputs, 2006–2009.

	China (1)	OECD (2)	non-OECD (3)	Global (4)=(1)+(2)+(3)
SO_x	−4,386,785	324,610	1,595,983	−2,466,191
	(−4,401,619)	(377,034)	(1,595,983)	(−2,428,601)
CO_2	−631,110	148,784	342,332	−139,994
	(−638,487)	(154,469)	(342,332)	(−141,686)

Notes: 1. This table shows the results of the analysis described in Section 3.3. SO_x in metric tons and CO_2 in thousand metric tons. 2. The figures in parentheses are the results of the calculations that include the 35 products in the industry "27t28" from Australia. 3. We cannot include the emissions for 2010 because the data for calculating the country-product-level emission intensity are not available for 2010 and beyond.

data. For each pollutant, the calculation proceeds in four steps. First, we obtain data on country-product-level emission intensity.[13] Second, we quantify the emissions in China if the imported intermediates were produced within the country. This is simple because we can easily obtain China's import volume for each intermediate from the trade transaction data. For each intermediate, multiplying the volume by China-specific product-level emission intensity yields "displaced" emissions due to importing that intermediate. Aggregating across all intermediates gives us total "displaced" emissions. Third, we calculate emissions in the source economies due to China's imports. Here, we use country-specific product-level intensities. Noting that China has quite a few trading partners, we classify the source countries into two groups according to whether they are members of the OECD.[14] Finally, we calculate the net effect on a global scale based on the findings from the previous two steps.

Table 1 summarizes the results for the period between 2006 and 2009. Note that there are 35 products with abnormal emission intensity in Australia.[15] To avoid their influence on the results, our calculation excludes them, although we also provide results that consider them for comparison. Column (1) represents the emissions "displaced" due to not producing these intermediates domestically. Columns (2) and (3) represent the emissions generated by China's imported intermediates sourced from OECD members and non-OECD members, respectively. Column (4) represents the net global effect of China's intermediate imports.

In summary, compared to domestic production of intermediate inputs, China's imports led to a decrease in global emissions.[16] During the four-year period, China's imported intermediates displaced SO_x (CO_2) emissions by as much as 4.4 (631.1) million tons. However, to produce these intermediate inputs, emissions in the source countries increased by only 1.9 (491.1) million metric tons. Furthermore, emissions from OECD members were significantly lower than those from non-OECD members,[17] likely due to relatively cleaner technologies in OECD members.

4. Empirical strategy

The primary objective of this study is to evaluate the effects of domestic environmental regulations on intermediate imports by downstream manufacturers in China. For the empirical investigations reported in this section, as discussed earlier in Section 3.1, we match the data of the trade transaction, ESR, and ASIF. The following Table 2 provides summary statistics for the main variables used in this section.

Given that firms can choose to import or not, it is essential to account for potential selection bias in our analysis. To address this, we construct the import probability at the firm-product level for each observation in our sample. Following existing literature (Amiti et al., 2017; Dahl, 2002; Das et al., 2003), we estimate an import participation equation with the following specification:

$$I_{fnt} = \alpha(s_n \times post_t) + X'_{fnt}\beta + \nu_1(lnShEl_{st} \times Foreign_f) + \nu_2(lnShEl_{st} \times SOE_f) + \gamma_f + \gamma_n + \gamma_{n2t} + \gamma_{pt} + \gamma_{st} + \varepsilon_{fnt}, \tag{1}$$

where I_{fnt} equals one if firm f (in 4-digit industry s) imports product n in year t and zero otherwise. s_n represents the *logged* emission intensity (i.e., SO_2 emission per unit of product n) if it were domestically manufactured in 2005 (one year before regulation started).

[13] We calculate emission intensities using information from the sources described in Section 3.1. Specifically, we match the WIOD-35 sectors with the 2-digit ISIC Rev.3 industry codes to calculate the industry-level emission intensity. The emission intensity of each 2-digit ISIC Rev.3 is defined as the emission intensity of its corresponding WIOD-35 sector. Next, the concordance table is used to bridge the HS 6-digit codes and the 2-digit ISIC Rev.3 industry codes, where a measure of emission intensity is obtained for each HS 6-digit product. A quick analysis shows that the emission intensity of products manufactured in China is generally higher than that of its trading partners.

[14] In this study, the OECD members considered include only those that joined the OECD before or during the year 2000: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

[15] We compare product-level emission intensity across countries and country groups. It indicates that the mean SO_x intensity of 35 products in the industry "27t28" from Australia is extremely high. As shown in Appendix Fig. A.2, it is approximately nine times higher than that of other OECD members and three and a half times higher than that of China between 2006 and 2009. We also note that the import volume of the 35 products from Australia represents approximately 0.5% of the total volume of China's imports.

[16] The findings are qualitatively the same if we use the input–output framework to make the calculation.

[17] In terms of import value, the import value from OECD members is roughly equal to that from non-OECD countries. From 2006 to 2009, the import value of intermediate goods from OECD members accounted for approximately 53% of China's total import value of intermediate goods.

Table 2
Summary statistics.

variable	mean	std. dev.	min.	max.
	A. firm-product-level (N = 2,877,682)			
$import$	8.186	2.890	0.589	15.873
s	−1.100	1.215	−7.490	3.102
$output$	11.576	1.686	8.379	17.264
K	10.037	1.911	5.270	15.662
K/L	4.113	1.483	−0.418	8.074
age	2.119	0.631	0	4.605
SOE	0.069	0.253	0	1
$exporter$	0.840	0.366	0	1
$ratio\_p$	0.508	0.487	0	1
$tariff$	0.085	0.048	0	1.216
$tariff \times ratio\_p$	0.047	0.059	0	1.216
	B. firm-level (N = 234,056)			
$output$	10.957	1.416	8.379	17.264
K	9.324	1.712	5.270	15.662
K/L	3.897	1.394	−0.418	8.074
age	2.056	0.673	0	4.605
SOE	0.0751	0.264	0	1
$exporter$	0.770	0.421	0	1
	C. product-level (N = 2701)			
s	−0.614	1.379	−7.490	3.102

Notes: 1. This table reports summary statistics for the key variables in the constructed dataset. 2. $import$ is imports of intermediates (US dollars, in log) at the firm-product-level. s is emission intensity of the products (metric tons per million RMB *yuan*, in log). $output$ is real output value of the firms (thousand RMB *yuan*, in log). K is real capital stock of the firms (thousand RMB *yuan*, in log). K/L is the ratio (thousand RMB *yuan* per person, in log) of the real capital stock to the number of employees of the firms. age equals one plus the difference between the current year and the birth year of the firms (in log). Dummy variables: $SOE = 1$ if the firm is a state-owned enterprise; $exporter$=1 if the firm exports. $ratio\_p$ is the proportion of processing imports at the firm-product-level. $tariff$ is import tariff rates of the products. $tariff \times ratio\_p$ is the interaction between the proportion of processing imports and import tariff.

The dummy variable $post_t$ equals one for the years during the Eleventh FYP period (2006–2010) when the new regulation was being implemented.

To control for potential confounding factors, Eq. (1) incorporates a vector of time-varying variables (X_{fnt}). It includes firm-level variables such as firm age, output value, capital stock, capital–labor ratio,[18] and two indicator variables: one indicating whether the firm exports and the other whether it is state-owned. Import tariff rates (a time-varying HS 6-digit product-level variable) are also included to control for trade policy effects. Additionally, the model includes firm fixed effects (γ_f) and product fixed effects (γ_n). Industry-specific factors affected the changes in mean emission intensity of imported intermediate inputs. For example, in Fig. A.1, after controlling for these factors, the mean intensity increased significantly during the Eleventh FYP period. A similar pattern emerges when considering product-specific factors. Therefore, the model includes product category (at the HS 2-digit level) by year fixed effects (γ_{n2t}) and CIC 4-digit industry by year fixed effects (γ_{st}). We also incorporate province by year fixed effects in the model to account for factors such as regulatory variations and regional development trends across provinces in China.

Following the approach of Amiti et al. (2017), we consider the effects of the share of firms with sufficient capital to be allowed to trade (denoted by $lnShEl_{st}$ in the equation, in log). Before 2004, Chinese firms faced a minimum registered capital requirement to obtain import and export rights, which means that there were strict access restrictions on whether a firm could engage in import business. To estimate a firm's probability of importing, it is crucial to control for the proportion of firms within the industry that had sufficient capital to obtain import rights. Given China's commitment to relaxing import restrictions on foreign firms upon joining the WTO, and considering that state-owned firms likely have better access to capital, we also interact $lnShEl_{st}$ with a foreign firm indicator ($Foreign$) and a state-owned firm indicator (SOE), respectively. Since we have controlled for CIC 4-digit industry by year fixed effects in the model, the impact of $lnShEl_{st}$ itself is absorbed. Finally, ε_{fnt} is an error term. We cluster the standard errors at the HS 6-digit product level.

It is essential to note that the Eleventh FYP established specific targets for reducing SO_2 emissions across various provinces. While the allure of employing a difference-in-difference-in-differences (DDD) model for our research is evident, we must consider the nuances. The province-specific regulations directly targeted polluting industries, but their impact on downstream firms, particularly those not directly regulated by the Eleventh FYP, is the primary interest of our paper. We posit that the regulatory variations across provinces had minimal influence on downstream firms not directly regulated by the Eleventh FYP. Assuming that transportation

[18] See notes under Table 2 for definitions for the variables.

costs within the unified national market are insignificant,[19] the price of a specific intermediate good should remain similar across provinces. Consequently, downstream firms base their import decisions primarily on price comparisons between the national and international markets. If the firms themselves were subject to province-varying regulation, the effects would be controlled by the province by year fixed effects. For these reasons, we choose the difference-in-differences (DD) model as our baseline model. However, it is worth noting that in subsequent sections of the paper, we present estimation results from the DDD model, further reinforcing our methodological choice.

We estimate the linear probability model (1) and predict the import probability of each firm-product-year observation. To estimate the effects of regulation on the value of imports, we address selection bias by using a fourth-order polynomial series of the predicted probabilities, $\sum_{i=1}^{4} \delta_i P^i$, to control the import probability. The specification of the baseline model is as follows:

$$import_{fnt} = \alpha(s_n \times post_t) + X'_{fnt}\beta + \sum_{i=1}^{4} \delta_i P^i_{fnt} + \gamma_f + \gamma_n + \gamma_{n2t} + \gamma_{pt} + \gamma_{st} + \varepsilon_{fnt}, \quad (2)$$

where $import_{fnt}$ represents the value of product n imported by firm f in year t (measured in log). Since $lnShEl_{st}$ only involves exclusive restrictions on import rights, it affects the probability of a firm obtaining import rights (import participation), but it does not directly influence the actual import volume of the firm. Foreign (or state-owned) firms will not choose to import more products simply because a higher proportion of firms in their industry have exceeded the threshold for obtaining import rights. Therefore, Model (2) includes all control variables and fixed effects in the import participation Eq. (1), except $lnShEl_{st}$ and its interactions with the foreign firm indicator or the state-owned firm indicator. Moreover, the vector X_{fnt} includes an additional variable that measures the firm's proportion of processing imports.[20] Considering that processing imports are exempted from import tariffs, we also control an interaction term between the proportion of processing imports and import tariff rates, which can absorb the effect of import tariffs and import structures.[21]

In contrast to Eq. (1), we follow Amiti et al. (2017) and do not include the two interaction terms between $lnShEl_{st}$ and the ownership indicators in Eq. (2) when estimating the impact of environmental regulations on the value of intermediate imports. This omission does not introduce endogeneity. As explained above, foreign (or state-owned) firms are unlikely to increase their import volumes solely because a higher proportion of firms in their industry surpasses the threshold for obtaining import rights.

In the baseline model (2), the coefficient of interest is α, which measures the effects of the regulation on intermediate imports. The identification assumption is that, conditional on the control variables, the regulation is independent of the error term. However, threats to identification may arise from other factors or policies that may influence firms' decision-making processes regarding imports. We will address identification threats in later sections of the paper.

5. Results

5.1. Main results

Table 3 summarizes the main results from estimating Eq. (2) using the constructed firm-product-level data.[22] Despite the differences in the fixed effects considered, all specifications lead to similar estimates for the impact of the regulation on intermediate imports, indicating that these estimates are robust. The results show that, compared to low-intensity intermediate inputs, the regulation induced firms to import more high-intensity intermediate inputs, and this effect is statistically significant. According to the preferred specification presented in column (3) that includes a complete set of fixed effects, every 1% increase in the SO_2 content of an intermediate good leads to an average increase of 0.026% in its imports after the implementation of the policy.

Although the baseline model includes fixed effects to account for industry, product, and province-specific shocks, the causal effect of the policy can only be correctly identified if the imports of high-intensity products exhibit similar trends to low-intensity products prior to the regulation. To evaluate the assumption, we estimate an event-study model,

$$import_{fnt} = \sum_t \alpha_t[s_n \times I(year = t)] + X'_{fnt}\beta + \sum_{i=1}^{4} \delta_i P^i_{fnt} + \gamma_f + \gamma_n + \gamma_{n2t} + \gamma_{pt} + \gamma_{st} + \varepsilon_{fnt}, \quad (3)$$

where $I(year = t)$ is an indicator variable that equals one if $year = t$. In this specification, the reference year is 2005. Fig. 3 reports the estimation results for the key coefficients, $\{\alpha_t\}$, and finds no pre-existing trend.

[19] If the transportation cost is high enough, import volume from the international market should be very small. Following Foster et al. (2008), we define 15 HS 6-digit products that involve boxes, concrete, and gasoline as high-transport-cost products. These products account for only 0.2% of the total import volume.

[20] The proportion of processing imports is measured by using imports through processing trade divided by total import. We use the variable to control the impact of import modes on imports.

[21] Due to the inclusion of firm observations that do not import, we are unable to control for the proportion of processing imports and its interaction with import tariff rates in the import participation Eq. (1). However, we can control these variables in Model (2).

[22] Appendix Table A.1 reports results from regressing the import participation Eq. (1).

Table 3
Impact of the regulation on intermediate imports.

	Dependent variable: $import_{fnt}$		
	(1)	(2)	(3)
$s_n \times post_t$	0.027**	0.026**	0.026**
	(0.012)	(0.012)	(0.012)
Control variables	Y	Y	Y
Firm FE	Y	Y	Y
Product FE	Y	Y	Y
HS2 by Year FE	Y	Y	Y
Province by Year FE		Y	Y
Industry by Year FE			Y
Observations	2,867,471	2,867,468	2,867,410

Notes: 1. This table presents the results obtained by estimating Model (2) while controlling for different sets of fixed effects. 2. s_n represents $logged$ emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 3. Control variables include firm's output value ($output$), capital stock (K), capital–labor ratio (K/L), age (age), ownership indicator (SOE), export status ($exporter$), and the proportion of processing imports ($ratio\_p$) and its interaction with product-level import tariff rates ($tariff \times ratio\_p$). Control variables also include import tariff rates and a fourth-order polynomial series of predicted probabilities. 4. Robust standard errors are in parentheses, clustered at the product level. ** $p < 0.05$.

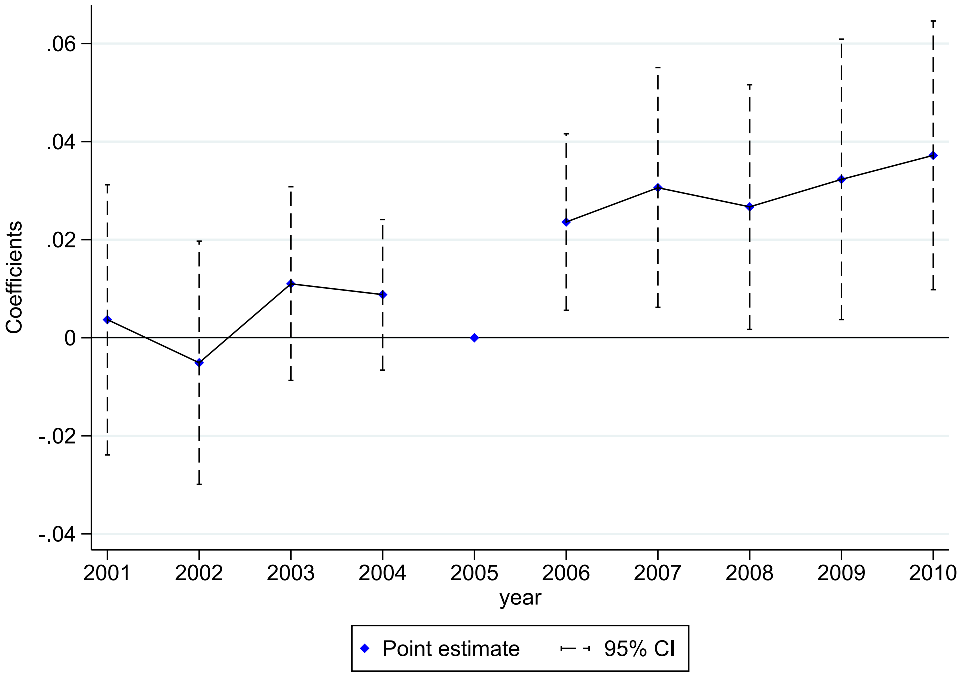

Fig. 3. Event-study results. *Notes*: This figure summarizes findings from estimating the event-study model (3). See the text for more information.

5.2. Identification threats

We interpret the above baseline estimate as the causal effect of regulation on intermediate imports. However, there are threats to identification. In this section, we examine whether our baseline result is confounded by other potential factors or policies.

Industry linkages. While our baseline regression attempts to control for demand and supply shocks to some extent by using a comprehensive set of fixed effects (such as industry by year fixed effects), the baseline results may still be biased if there are industry shocks (especially from downstream industries) that are not taken into account. For example, an increase in demand in downstream industries can lead to increased imports of intermediate inputs from upstream sectors. To address this concern, for each firm in our sample, we collect data on the output value of the downstream industries. For the downstream industries, we use input and output shares from the 2002 Input–Output Table and simply aggregate the output value of all firms at the city-industry-year level. We then include the output value of the downstream industries (in log) in the baseline regression. Column (1) of Table 4 reports the results, indicating that the main finding from the baseline regression still holds.

Input composition. A firm's input composition may change over time due to various reasons, such as shifts in its production technology. If the changes in the determinants of input demand are correlated with the policy, it can bias our baseline estimate of the policy's effect on intermediate imports. Specifically, does the firm increase its imports due to a rise in overall demand for intermediate inputs (including imported ones)?

To examine this question, one needs to identify the magnitude of changes in the import of emission-intensive inputs by firms after the implementation of the policy. Subsequently, we can further investigate whether this change is accompanied by an increase in the total intermediate inputs of the firms. Note that total intermediate inputs (but not by sources of inputs) of a firm are recorded using a single variable in the firm-level ASIF data, while information on imported intermediate inputs is available at the firm-product level in the trade data. Using trade data, we construct the main explanatory variable: changes in emission intensity for imported intermediate inputs during the Eleventh FYP. This approach is inspired by the method for measuring fiscal pressure (Chen, 2017). First, we split the data into two periods: 2001–2005 and 2006–2010. Second, for each firm in each period, we calculate the value-weighted emission intensity. Third, for each firm, we obtain the difference in intensity between the two periods, Δs_f. It measures the changes in the product structure of firms before and after the initiation of the regulation. Formally,

$$\Delta s_f = log \frac{\sum_{t=2006}^{2010} \sum_n M_{fnt} \times S_n}{\sum_{t=2006}^{2010} \sum_n M_{fnt}} - log \frac{\sum_{t=2001}^{2005} \sum_n M_{fnt} \times S_n}{\sum_{t=2001}^{2005} \sum_n M_{fnt}},$$

where $M_{fnt} = exp(import_{fnt})$ and $S_n = exp(s_n)$.

We then estimate the following equation

$$Y_{ft} = \alpha(\Delta s_f \times post_t) + \theta x'_{ft} + \gamma_f + \gamma_{pt} + \gamma_{st} + \varepsilon_{ft}. \tag{4}$$

Since we use firm-level data in Eq. (4), we can account for time-varying firm-level variables, such as firm age, output value, capital stock, capital–labor ratio and a dummy variable for export status. Furthermore, Eq. (4) incorporates firm fixed effect, province by year fixed effects, and CIC 4-digit industry by year fixed effects. Standard errors are clustered at the city level. The coefficient of interest is α, which measures the effects of the policy on the total intermediate inputs of firms. As shown in column (2), the effect is statistically insignificant. This implies that the policy did not increase the use of intermediate inputs by the firms. The increase in imported emission-intensive intermediates did not result in an overall increase in total intermediate inputs for firms.

International market. To account for changes in foreign demand for the firm's manufactured goods, we conduct a sensitivity analysis using the ASIF data again. Specifically, we examine the effects of changes in mean emission intensity (Δs_f) on firm exports. Column (3) finds no statistically significant effects. On the supply side in the international market, there are also factors that can affect import decisions made by Chinese firms. To test for potential bias from omitting such factors, we use information on the source country in the trade transaction data and construct larger firm-product-country-level data. We then estimate a model similar to Eq. (2) and control country by year fixed effects, which absorb time-varying factors related to source countries, such as regulatory stringency and other supply-side shocks. Column (4) finds that, even after considering the time-varying shocks from source countries, our baseline finding remains consistent.

Import tariff rates adjustment. We speculate whether China's trade policy is affected by environmental concerns. For example, Eisenbarth (2017) finds that environmental considerations in China drove export VAT rebate rates, but not export taxes. In our case, the focus is on import tariff rates, which are one of the important factors affecting firm intermediate imports. Generally, heavily-emitting products have lower tariff rates (Shapiro, 2021). Our specific concern is whether the downward adjustment of import tariff rates for higher emissions-intensive products is simultaneous with the tightening of environmental regulations during the Eleventh FYP period. If that is the case, it may bias our baseline estimate of the impact of environmental policy on intermediate imports. Although the baseline regression already controls for import tariff rates of the HS 6-digit products, we conduct a specific analysis using the product-level data and estimate the following equation.

$$tariff_{nt} = \alpha(s_n \times post_t) + \gamma_n + \gamma_{n2t} + \varepsilon_{nt}, \tag{5}$$

where $tariff_{nt}$ represents the import tariff rate of product n in year t. The equation includes product fixed effects and HS 2-digit product category by year fixed effects. Standard errors are clustered at the product level. Column (5) of Table 4 reports the results show that import tariff rates for intermediates with higher emission intensity have not changed after the Eleventh FYP, which helps address the concern that environmental policies affect import tariff rates and thus increase imports of intermediates.

Other trade policies. Other non-tariff trade policies can impact how firms engage in import activities. We check if our baseline result is confounded by concurrent trade policies. After conducting a comprehensive review, we determined that the most pertinent trade policy is related to import permits. Following China's accession to the WTO in late 2001, the country gradually eliminated its import restrictions. For example, in 2001, there were 129 HS 6-digit products that required an import permit. This number decreased to 61 in 2002 and 10 in 2008. As a check, we add a new control variable: the share of a firm's imports that are not subject to import restrictions, and re-estimate the baseline model. As shown in column (6) of Table 4, our baseline results remain unchanged.

Other environmental and energy policies. We conducted a review and believe that the most relevant policy is the TOP-1k program (Price et al., 2010). The central government launched the program in 2006 with the aim of increasing the energy efficiency of 1,008 industrial firms in nine energy-intensive industries. We drop the firms and re-estimate the baseline model (2) with a slightly smaller sample. Column (7) of Table 4 presents the results, which show that our baseline results remain consistent.

Table 4
Checks on confounding factors.

	$import_{fnt}$ (1)	$intermediates_{ft}$ (2)	$export_{ft}$ (3)	$import_{fnct}$ (4)	$tariff_{nt}$ (5)	$import_{fnt}$ (6)	$import_{fnt}$ (7)	$import_{fnt}$ (8)
$s_n \times post_t$	0.025**			0.026*	−0.0002	0.025**	0.026**	0.036**
	(0.012)			(0.015)	(0.0004)	(0.012)	(0.012)	(0.016)
$\Delta s_f \times post_t$		0.005	0.026					
		(0.005)	(0.043)					
Downstream value	Y							
Other control variables	Y	Y	Y	Y		Y	Y	Y
Firm FE	Y	Y	Y	Y		Y	Y	Y
Product FE	Y			Y	Y	Y	Y	Y
HS2 by year FE	Y			Y	Y	Y	Y	Y
Province by Year FE	Y	Y	Y	Y		Y	Y	Y
Industry by Year FE	Y	Y	Y	Y		Y	Y	Y
Country by Year FE				Y				
Observations	2,829,025	18,470	24,831	4,134,954	26,378	2,867,217	2,856,081	2,866,619

Notes: 1. This table shows the results of various checks on confounding factors. See the text for more information. 2. s_n represents *logged* emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010); Δs_f represents the difference in intensity between the two periods for firm f. 3. Due to the availability of data on intermediates, column (2) is based on the ASIF data for years from 2001–2007. 4. Columns (1), (6), (7), and (8) utilize firm-product-level data. Columns (2) and (3) are based on firm-level data. Columns (4) and (5) use firm-product-country-level data and product-level data, respectively. 5. In columns (1), (4), (6), (7) and (8), control variables include $output$, K, K/L, age, SOE, $exporter$, $ratio\_p$, $tariff$, $tariff \times ratio\_p$ and a fourth-order polynomial series of predicted probabilities. Column (6) additionally controls the share of imports of a firm that are not subject to import restrictions. Column (8) additionally controls the interaction terms between COD emission intensity and $post_t$. Columns (2) and (3) control $output$, K, K/L, age, SOE, and $exporter$. 6. Robust standard errors are clustered at the product level for columns (1), (4), (5), (6), (7), and (8) and at the city level for columns (2) and (3). Robust standard errors are reported in parentheses. * $p < 0.1$, ** $p < 0.05$.

Furthermore, the Eleventh FYP not only imposed restrictions on SO_2 emissions, but also regulated chemical oxygen demand (COD) emissions. We use SO_2 emission intensity as a proxy for the stringency of environmental regulation to which a product is subject, which may overlook the impact of COD regulations on imports. To address this concern, we additionally control for the interaction between the COD emission intensity (in log) and $post_t$ in Model (2). Column (8) of Table 4 finds similar results.

5.3. Channels

Regulating the production of emission-intensive intermediate goods in the upstream industries could affect the imports of a downstream firm through two channels. First, the importing downstream firm began to purchase more of the products they already imported prior to the regulation (that is, the intensive margin). Second, it provides incentives for non-importers to become importers (i.e., the extensive margin).

To investigate the role of intensive margin, we additionally control for firm-product-level unobservable factors by using firm-product fixed effects in the baseline regression. Column (1) of Table 5 shows that the estimated coefficient is positive and statistically significant, indicating the presence of the intensive margin. However, the magnitude is smaller than the baseline result. This suggests that the intensive margin alone cannot fully account for the overall effect of the policy on imports. To investigate the extensive margin, we define a dummy variable: $entry_{fnt} = 1$ if firm f started importing product n in year t (for any $t > 2001$, as 2001 is the first year in our data sample). Due to data constraints and the survey method, we do not analyze the impacts on firm exits.[23]

Columns (2)-(4) consider all intermediate imports, normal trade, and processing trade, respectively. The findings show that, in any type of trade, the policy encourages non-importers to become buyers of intermediate goods in the international market. Furthermore, these effects are more pronounced for products with higher emission intensity.

In addition, we investigate a firm's import behavior, including the composition of products and importing frequencies. We then introduce a new variable called *Ratio*, which measures the share (in log) of the import value of an intermediate product in the firm's total import value of intermediates. A regression using *Ratio* as the outcome variable suggests that the policy increases this share, with a larger effect observed for products with higher emission intensity. It means that firms import relatively more of highly-emitting products after the policy's implementation. Column (5) of Table 5 summarizes the results. Column (6) examines the frequency (in log) of importing for each firm-product-year observation. We observe a positive and statistically significant ($p = 0.115$) coefficient for the variable of interest.

We previously argued that stricter regulations raise the cost of producing emission-intensive intermediates, which could be passed through to downstream industries in the form of higher prices. This provides incentives for importers in downstream industries to import and encourages more firms to engage in importing. To verify this assertion, we would ideally need extensive data on production and demand to disentangle the effects of regulation on marginal cost and product price. Unfortunately, we lack

23 The "disappearance" of one firm in ASIF dataset does not necessarily indicate an actual exit. It could be due to various reasons, such as their sales falling below 5 million yuan in a given year, bankruptcy, restructuring, or even changes in their name. It is then very challenging for us to correctly define firm exit.

Table 5
Channels.

	$import_{fnt}$ (1)	$entry^{a}_{fnt}$ (2)	$entry^{n}_{fnt}$ (3)	$entry^{p}_{fnt}$ (4)	$Ratio_{fnt}$ (5)	$freq_{fnt}$ (6)
$s_n \times post_t$	0.020*	0.0016**	0.0022***	0.0009*	0.029**	0.012
	(0.011)	(0.0007)	(0.0006)	(0.0005)	(0.012)	(0.008)
Control variables	Y	Y	Y	Y	Y	Y
Firm FE		Y	Y	Y	Y	Y
Product FE		Y	Y	Y	Y	Y
Firm by Product FE	Y					
HS2 by Year FE	Y	Y	Y	Y	Y	Y
Province by Year FE	Y	Y	Y	Y	Y	Y
Industry by Year FE	Y	Y	Y	Y	Y	Y
Observations	2,157,290	9,461,797	9,461,797	9,461,797	2,867,410	2,867,408

Notes: 1. This table shows the results from analyzing the channels through which the regulations affected intermediate imports. Column (1) examines the intensive margin. For columns (2)–(4), $entry_{fnt} = 1$ if firm f started importing product n in year t (for any $t > 2001$, as 2000 is the first year in our data sample). The three columns differ in the samples (i.e., all trade, normal trade, and processing trade, respectively) used for regressions. These columns do not control the proportion of processing imports and the interaction term between proportion of processing imports and import tariff rates. We exclude observations with real output value, real capital stock and the ratio of the real capital stock to the number of employees in the 0.5% tails. For column (5), the outcome variable $Ratio$ measures the share of the value of the product in a firm's total import value. The outcome variable for column (6) is the frequency of import for each firm-product-year observation. 2. s_n represents $logged$ emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 3. In columns (1), (5), and (6), the control variables include $output$, K, K/L, age, SOE, $exporter$, $ratio\_p$, $tariff$, $tariff \times ratio\_p$ and a fourth-order polynomial series of the predicted probabilities. In columns (2), (3), and (4), the control variables include $output$, K, K/L, age, SOE, $exporter$ and $tariff$. 4. Robust standard errors clustered at the product level are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Import prices of intermediates.

	Dependent variable: $price_{fnt}$		
	(1)	(2)	(3)
$s_n \times post_t$	0.024	0.024	0.024
	(0.016)	(0.017)	(0.017)
Control variables	Y	Y	Y
Firm FE	Y	Y	Y
Product FE	Y	Y	Y
HS2 by Year FE	Y	Y	Y
Province by Year FE		Y	Y
Industry by Year FE			Y
Observations	2,765,970	2,765,967	2,765,909

Notes: 1. This table displays the results of assessing the impact of regulation on intermediate import prices. We control for different sets of fixed effects. 2. s_n represents $logged$ emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 3. Control variables include $output$, K, K/L, age, SOE, $exporter$, $ratio\_p$, $tariff$, $tariff \times ratio\_p$ and a fourth-order polynomial series of predicted probabilities. 4. Robust standard errors are reported in parentheses, clustered at the product level.

information on domestic market prices during the regulation period. As an alternative approach, we utilize the prices of imported intermediates to provide some suggestive evidence explaining the reasons for the increase in imports after the Eleventh FYP. Specifically, we use firm-product-year-level import prices as the outcome variable and estimate a model similar to Eq. (2). Table 6 summarizes the results based on different fixed effects. We find that the coefficients of the variable of interest ($s_n \times post_t$) are positive in all specifications, with p values are around 0.14. The finding implies that the regulation led to an increase in equilibrium prices.

6. Additional evidence

6.1. Robustness checks

In this subsection, we check if the baseline estimates are robust.

Levels for clustering standard errors. For the previous regressions, standard errors are clustered at the product level. We also cluster standard errors at the product and CIC 4-digit industry level to account for autocorrelation within industry-product groups. In the other two checks, we use the product and city level and the product and province level. The results summarized in rows (1)-(3) of Fig. 4 confirm that the estimates remain statistically significant.

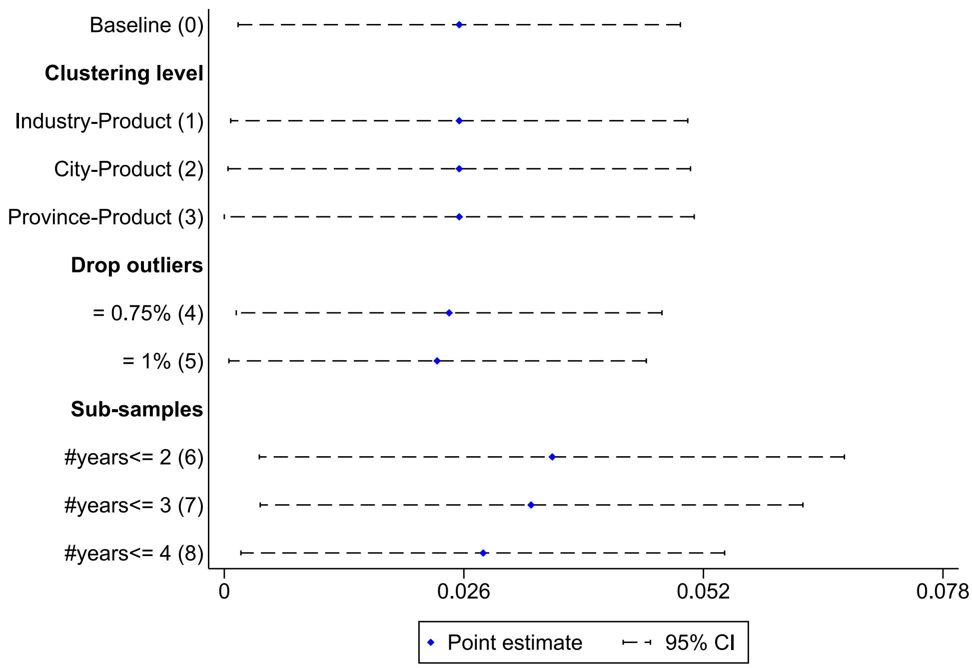

Fig. 4. Robustness check.
Notes: Row 0 reports the baseline result. Rows 1–3 use different levels to cluster the standard error. Rows 4 and 5 use different samples that exclude outliers with different definitions. Rows 6–8 checks if the baseline result is driven by a subset of firm observations that appear in some of the years during the time period. For example, row 6 uses only the firms that import in one or two years after the regulation (2006–2010). See the text for more explanations.

Outliers. To exclude the influence of outliers that might still exist in the sample on the baseline regressions, we drop observations where imports of intermediates are at the 0.75% and 1% tails, respectively. Rows (4) and (5) of Fig. 4 show that the estimates remain statistically significant.

Subsamples. To check if our baseline result is driven by specific subsets of firm observations that appear in some of the years during the time period, we use different subsamples to re-run the baseline regression. For example, we use only the firms that import in one or two years after the regulation (2006–2010), and we do the same for other subsamples based on how many years they imported. Rows (6)-(8) of Fig. 4 demonstrate that the main coefficient of interest remains robust across all subsamples, including firms that import temporarily or continuously after the policy was implemented.

Trade transaction data. In addition to the above checks, we also estimate the effects using the entire trade transaction data. The advantage of using the data is that it includes all import transactions, while the disadvantage is that we cannot control for firm-level time-varying variables. However, as shown in the Appendix Table A.2, the coefficient is quite close to the baseline estimate.

6.2. DDD specification

As noted earlier, the stringency of regulating the production of intermediate goods that are emissions-intensive differs between provinces within the country. We have provided the reasons for using the DD model instead of the DDD model in the preceding text. On one hand, we should not overlook the fact that China is a unified market. If we assume that the transaction costs between provinces are too high to compensate for the shortage of intermediates through domestic trade, then this obstacle should be more prominent in international trade. Unlike production and export activities, within a unified market, firms located in regions with stricter regulations can preferentially purchase intermediates from regions with relatively lax regulations before importing, which could diminish regional import differences. Therefore, we believe that import differences between provinces caused by environmental regulations should be very weak. On the other hand, we have controlled for province by year fixed effects in the baseline analysis to address the potential effects. However, to further elucidate the potential interference of these specific influences on the baseline findings, we employ a DDD model to check. The specification is as follows:

$$import_{fnt} = \alpha(s_n \times post_t \times target_p) + X'_{fnt}\beta + \sum_{i=1}^{4} \delta_i P^i_{fnt} + \gamma_f + \gamma_{nt} + \gamma_{pn} + \gamma_{st} + \gamma_{pt} + \varepsilon_{fnt}, \tag{6}$$

where $target_p$ is the pollution reduction target for province p. We absorb the remaining interaction terms by adding fixed effects. As shown in Table 7, despite differences in fixed effects, all specifications yield similar results, where the coefficient of $s_n \times post_t \times target_p$

Table 7
Impact of the regulation on intermediate imports (DDD estimates).

	Dependent variable: $import_{fnt}$		
	(1)	(2)	(3)
$s_n \times post_t \times target_p$	0.093	0.080	0.085
	(0.057)	(0.057)	(0.057)
$post_t \times target_p$	−0.478***	−0.391***	
	(0.107)	(0.107)	
Control variables	Y	Y	Y
Firm FE	Y	Y	Y
Product by Year FE	Y	Y	Y
Product by Province FE	Y	Y	Y
Industry by Year FE		Y	Y
Province by Year FE			Y
Observations	2,857,793	2,857,736	2,857,730

Notes: 1. This table presents the results from estimating Model (6) while controlling for different sets of fixed effects. 2. s_n represents *logged* emission intensity of product n; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010); $target_p$ represents emission reduction target for province p. 3. Control variables include $output$, K, K/L, age, SOE, $exporter$, $ratio\_p$, $tariff \times ratio\_p$ and a fourth-order polynomial series of predicted probabilities. 4. Robust standard errors are in parentheses, clustered at the product-province level. *** $p < 0.01$.

is positive but fails the 10% significance test. This result confirms our hypothesis that although there are differences in the stringency of environmental regulation among provinces, the import differences between provinces have been weakened by domestic trade due to the free flow of goodsfloat domestically.

6.3. Heterogeneity

We interpret the baseline estimate as the average effect of the policy on intermediate imports. To check whether the effect varies across different firm or firm-product groups, we perform several heterogeneity analyses.

Firm's reliance on imported intermediates. After the implementation of this policy in the upstream industries, firms can passively choose to import intermediates with high emission intensity. However, a firm's degree of import penetration in its total intermediate inputs may affect its changes in import behavior. To investigate this, we calculate the degree of a firm's reliance on imported intermediates before 2006 and classify the firms into two groups according to the degree. The degree is measured by the ratio of the value of intermediate imports to the total of intermediate inputs. If a firm's degree is higher than the median of the associated CIC 4-digit industry, it is assigned to the "high" group; otherwise, it enters the "low" group.

Panel A of Table 8 reports the results from two separate regressions using the two subsamples. The results are consistent with the baseline results. However, the estimate for the low-dependence firms is slightly smaller than that for the other group of firms. One possible explanation for this difference is that firms with a high dependence on imported inputs are relatively less affected by the domestic market of intermediate inputs, while firms with a low dependence face greater pressure from upstream regulation.

Firm's diversity of import sources. The impact of the policy on import may also depend on the firm's diversity of import sources.[24] First, firms with higher diversity may find it more convenient to increase intermediate imports when needed. Additionally, diversity provides firms with more choices in input decisions, such as upgrading their input composition, rather than solely importing more emission-intensive intermediates. Again, we use the median diversity in a 4-digit industry to classify firms into two groups. Panel B of Table 8 reports the results of the two regressions with the two groups of firm observations. Both estimates are positive and statistically significant. However, the apparent difference in the magnitude of the coefficients indicates that firms with lower diversity of import sources experienced greater increases in imports of emissions-intensive intermediates after the implementation of the regulation.

Different source countries: OECD vs non-OECD. The final heterogeneity is about the different characteristics of the source countries. Different source countries of imported intermediates play an important role in supplying the type and quality of imports. We classify the firm-product-country-year observations into two groups based on whether the source country is an OECD member or not. Panel C of Table 8 reports the results. The findings show that more imported intermediates are sourced from the OECD group after the policy, rather than from the non-OECD group. In other words, China's imports of emission-intensive intermediates resulting from the Eleventh FYP primarily sourced from economically advantageous countries compared to China.

[24] The diversity here is defined as the number of source countries for intermediates imported by the firm within the pre-regulation period from 2001–2005.

Table 8
Heterogeneity analysis.

	Dependent variable: $import_{fnt}$					
	A. Reliance		B. Diversity		C. Country groups	
	(1) high	(2) low	(3) high	(4) low	(5) OECD	(6) non-OECD
$s_n \times post_t$	0.025**	0.031*	0.020*	0.072**	0.032***	0.011
	(0.012)	(0.016)	(0.012)	(0.030)	(0.011)	(0.020)
Control variables	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Product FE	Y	Y	Y	Y	Y	Y
HS2 by Year FE	Y	Y	Y	Y	Y	Y
Province by Year FE	Y	Y	Y	Y	Y	Y
Industry by Year FE	Y	Y	Y	Y	Y	Y
Observations	2,249,913	366,385	2,245,647	427,374	2,193,937	1,037,088

Notes: 1. This table presents the results from heterogeneity analysis. The model specification aligns with Model (2), but we examine different subsamples. See the text for more information on these subsamples. 2. s_n represents *logged* emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 3. Control variables include $output$, K, K/L, age, SOE, $exporter$, $ratio\_p$, $tariff$, $tariff \times ratio\_p$ and a fourth-order polynomial series of the predicted probabilities. 4. Robust standard errors, clustered at the product level, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6.4. Environmental implications

The strengthening of environmental regulations in the Eleventh FYP has encouraged Chinese manufacturers to import more emission-intensive intermediate inputs, which has undoubtedly impacted the global environment. On one hand, it reduced emissions within China by outsourcing intermediates to foreign economies. On the other hand, it caused the emissions from the source countries to increase due to their growth in production and exports to China. But what are the relative importance of these two effects, and what are the net environmental impacts? This subsection attempts to answer these questions through a simple back-of-the-envelope calculation.

We estimate the changes in imports induced by the regulation. Given the nature of the difference-in-differences model, we need to choose a reference product for the estimation. As an exercise, we use a product with SO_2 emission intensity (in log) at the 25th quantile, denoted as s_b, as the reference product. For any other product with a $logged$ intensity s (where $s > s_b$), relative to the reference product, its change in $logged$ imports induced by the regulation is given by $\Delta_b \equiv 0.026 \times (s - s_b)$ where 0.026 is the estimated coefficient reported in Table 3. Thus, the change in imports of the product is

$$M \times [exp(\Delta_b) - 1]/exp(\Delta_b).$$

For each product-country observation, we know the import value, denoted as M. Therefore, we can calculate the emissions of SO_x if the induced intermediate imports were produced in China and the emissions in the source country.[25] Similarly, we report the findings after grouping the countries based on whether they are members of the OECD or not. The first row of Table 9 summarizes the results of the calculations for SO_x emissions. As in Section 3.3, we consider both cases with and without inclusions of the 35 products from Australia with extremely high levels of SO_x emission intensity.

Table 9 also reports the calculated changes in CO_2 emissions induced by the regulation. Overall, Panel A of the table shows that, relative to the emissions of the reference product, the policy in China reduced global emissions of SO_x (and CO_2) from the production of intermediate inputs with a higher emission intensity by about 22.7 thousand metric tons and 3.3 million metric tons, respectively. Notably, OECD members generally exhibit lower emission intensities. By importing a certain amount of products from other sources rather than producing the same amount domestically, China's regulation contributed to the reduction of global emissions.

The choice of the reference product surely impacts the estimated environmental impacts of the regulation. Panels B and C provide two additional examples. The calculations use products with median emission intensity and products at the 75th quantile as the reference, respectively. Appendix Table A.3 presents environmental implications of the regulation using estimates from the heterogeneity analysis (specifically, 0.032 for OECD members and 0.011 for non-OECD members, as shown in Table 8). Importantly, all calculations yield qualitatively similar results, demonstrating that the regulation contributed to the decreases in global emissions.

7. Conclusion

This paper provides new evidence at the firm-product level regarding the impact of domestic environmental regulation on intermediate imports. Our findings indicate that China's stricter air quality regulation for industries with high sulfur dioxide emission

[25] Note that Section 3.3 describes how to obtain data on country-product-level emission intensities. When calculating the changes in imports of a product, we use the calculated emission intensity for China in 2005. When calculating the changes in emissions induced by the regulation in a year from 2006–2009, we then use the country-product-level emission intensity calculated from the WIOD data for that year.

Table 9
Environmental effects of the regulation, 2006–2009.

	Induced changes in emissions			
	China (1)	OECD (2)	non-OECD (3)	Global (4) = (1)+(2)+(3)
	A. Relative to products with SO_2 intensity at the 25th quantile			
SO_x	−48,885	8632	17,516	−22,736
	(−49,835)	(12,002)	(17,516)	(−20,317)
CO_2	−14,266	3928	7009	−3329
	(−14,742)	(4295)	(7009)	(−3439)
	B. Relative to products with median SO_2 intensity			
SO_x	−10,425	2513	3416	−4496
	(−10,950)	(4380)	(3416)	(−3155)
CO_2	−3947	1089	1574	−1284
	(−4212)	(1293)	(1574)	(−1345)
	C. Relative to products with SO_2 intensity at the 75th quantile			
SO_x	−2,821	836	1,008	−977
	(−3116)	(1891)	(1008)	(−217)
CO_2	−1143	322	540	−281
	(−1294)	(438)	(540)	(−317)

Notes: 1. This table shows the results from calculating the environmental impacts of the regulation. We use baseline estimates about the effects of regulation on imports. See also Section 6.4 in the text for details. SO_x in metric tons and CO_2 in thousand metric tons. 2. The numbers in parentheses are results from the calculations that include the 35 products in the industry "27t28" from Australia. 3. An intermediate product with SO_2 intensity near the 25th quantile is "polypropylene" (HS 6-digit code: 390210). Its total import value from 2006 to 2010 was 26 billion US dollars. Other products with the same SO_2 intensity include "Polyethylene having a specific gravity of 0.94 or more" (HS 6-digit code: 390120) and "acrylonitrile-butadiene-styrene copolymers (ABS)" (HS 6-digit code: 390330). An intermediate product with SO_2 intensity near the 50th quantile is "iron ores and concentrates, non-agglomerated" (260111). Its total import value from 2006 to 2010 was 82.8 billion US dollars. Other products with the same SO_2 intensity include "Copper ores and concentrates" (260300) and "iron ores and concentrates, agglomerated" (260112), etc. An intermediate product with SO_2 intensity near the 75th quantile is "terephthalic acid and its salts" (291736). Its total import value from 2006 to 2010 was 22.8 billion US dollars. Other products with the same SO_2 intensity include "styrene" (290250) and "p-xylene" (290243), etc. 4. Data for calculating country-industry emission intensity are not available for 2010 and beyond.

intensity, established by the Eleventh FYP for Environmental Protection (covering 2006–2010), induced downstream manufacturers to increase their imports of emission-intensive intermediate inputs. Specifically, a 1% increase in the emission intensity of an intermediate input was associated with a 0.026% increase in intermediate imports following the implementation of the regulation. The finding suggests that behind-the-border environmental regulation also plays a role in outsourcing in the Global South context.

We also investigate environmental implications of the regulation through a simple back-of-the-envelope calculation. The results suggest that although the regulation increased sulfur oxide emissions in the source countries, it ultimately reduced global emissions. This outcome arises because the increased imports primarily came from countries with lower emission intensity than China. Our analysis also indicates that the regulation did not disproportionately increase imports or sulfur dioxide emissions from developing countries. The conclusions also extend to emissions of carbon dioxide, a global pollutant and co-pollutant of sulfur oxides in many industries. In sharp contrast to previous studies in developed economies, our results suggest that air quality regulation in a developing country may not only reduce air pollution concentrations domestically, but may also bring climate benefits worldwide.

In closing, two open questions remain for future research. First, while our analysis demonstrates that environmental regulation targeting specific industries affected downstream industries, quantifying the economic cost-sharing between regulated and downstream industries remains an open question. Future work could explore this issue when relevant data (such as product prices and quantities of specific intermediate inputs purchased by firms from the domestic market) become available. Second, although our findings deepen our understanding of the broad effects of regulation. However, given the main purpose of the paper, quantifying the welfare gains resulting from the regulation remains an important avenue for further exploration.

CRediT authorship contribution statement

Chao Han: Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Chongyu Li:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Jiansuo Pei:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Chunhua Wang:** Writing – original draft, Writing – review & editing, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no relevant or material financial interests that relate to the research described in this article.

Appendix

See Figs. A.1 and A.2 and Tables A.1–A.3.

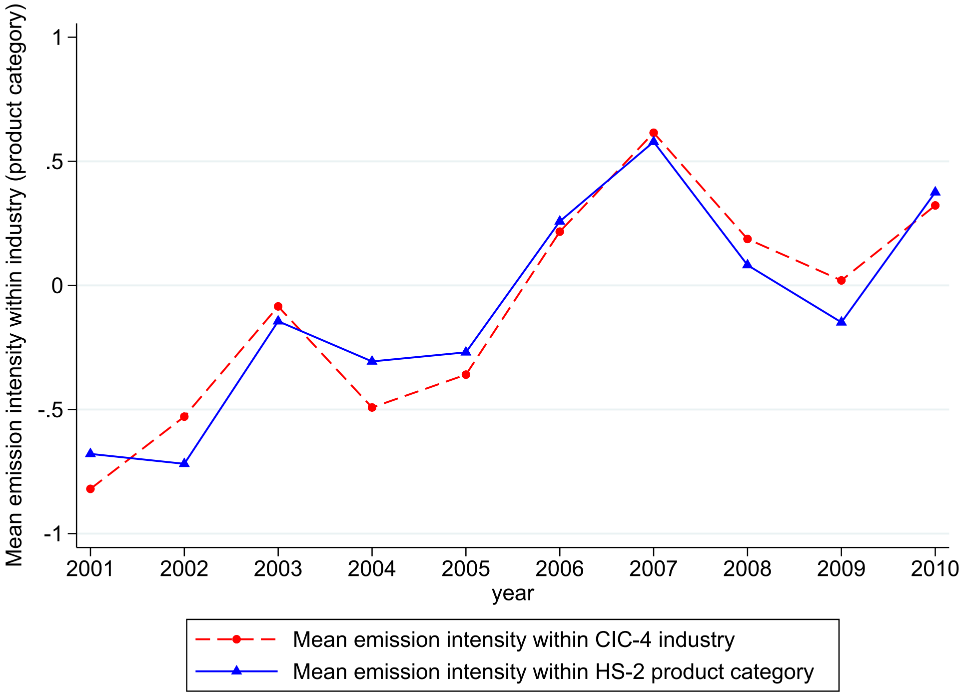

Fig. A.1. Annual average SO_2 emission intensity of imported intermediates within industry or product category.
Notes: The dashed line represents the trend of the annual average SO_2 emission intensity of imported intermediates within China's CIC 4-digit industry. The solid line corresponds to the annual average intensity within the HS 2-digit product category. Here's how these values are calculated: First, regress firm-product-level emissions on industry fixed effects (or HS 2-digit product category fixed effects) and obtain the residuals. Second, sum up these residuals by year. Third, divide the total sum by deflated total value (using the import price index with 2001 as the base year). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

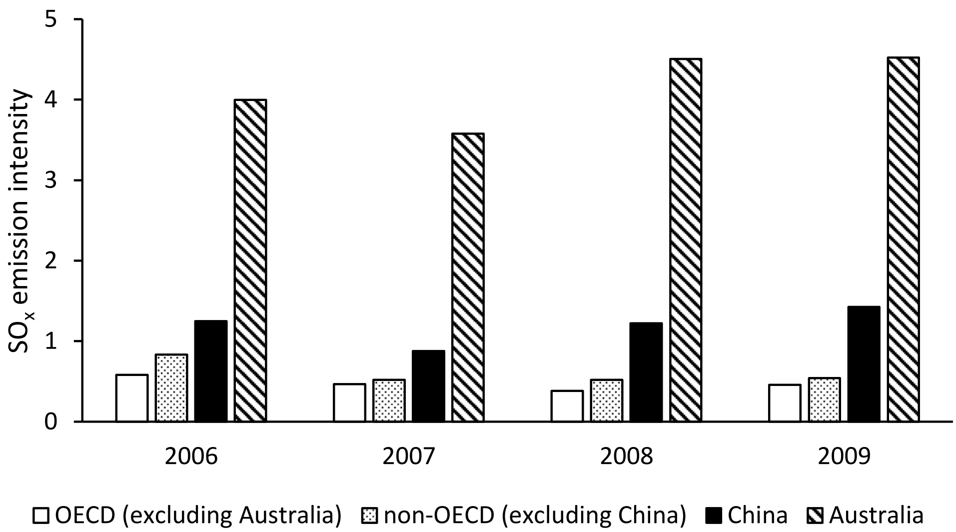

Fig. A.2. Emission intensity of 35 specific products in sector 27t28.
Notes: This figure illustrates the SO_x emission intensity of 35 products in the OECD, non-OECD, China, and Australia. The unit of intensity is metric tons per million US dollars.

Table A.1
Impact of the regulation on import participation.

	Dependent variable: I_{fnt} = 1 if $import_{fnt}$>0		
	(1)	(2)	(3)
$s_n \times post_t$	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)
$output_{ft}$	0.029***	0.038***	0.037***
	(0.001)	(0.001)	(0.001)
K_{ft}	0.060***	0.057***	0.056***
	(0.001)	(0.001)	(0.001)
K_{ft}/L_{ft}	−0.030***	−0.036***	−0.035***
	(0.001)	(0.001)	(0.001)
age_{ft}	−0.001	−0.002**	−0.000
	(0.001)	(0.001)	(0.001)
SOE_{ft}	−0.000	−0.000	−0.001
	(0.001)	(0.001)	(0.001)
$exporter_{ft}$	0.026***	0.025***	0.024***
	(0.001)	(0.001)	(0.001)
$tariff_{nt}$	−0.128	−0.122	−0.126
	(0.116)	(0.115)	(0.115)
$lnShEl_{st}$	0.216***	0.239***	
	(0.009)	(0.009)	
$lnShEl_{st} \times foreign_{ft}$	−0.238***	−0.256***	−0.238***
	(0.007)	(0.007)	(0.007)
$lnShEl_{st} \times SOE_{ft}$	−0.044**	−0.059***	−0.082***
	(0.008)	(0.007)	(0.007)
Firm FE	Y	Y	Y
Product FE	Y	Y	Y
HS2 by Year FE	Y	Y	Y
Province by Year FE		Y	Y
Industry by Year FE			Y
Observations	9,881,902	9,881,893	9,881,877

Notes: 1. This table shows the results from estimating Model (1) by controlling different sets of fixed effects. s_n represents *logged* emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 2. The import probabilities estimated in columns (1), (2) and (3) are controlled in the respective columns of Table 3, respectively. 3. Due to the inclusion of firm observations that do not import, we are unable to control for the proportion of processing imports and its interaction with import tariff rates. 4. Given that $lnShEl_{st}$ is time-varying industry-level variable, it is absorbed by fixed effects in column (3). 5. Robust standard errors, clustered at the product level, are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

Table A.2
Impact of the regulation on intermediate imports: Trade transaction data.

	Dependent variable: $import_{fnt}$	
	(1)	(2)
$s_n \times post_t$	0.028**	0.028**
	(0.013)	(0.013)
Control variables	Y	Y
Firm FE	Y	Y
Product FE	Y	Y
HS2 by Year FE	Y	Y
Province by Year FE		Y
Observations	10,170,643	7,689,429

Notes: 1. s_n represents *logged* emission intensity of product n in 2005; the dummy variable, $post_t$, is equal to 0 for 2001–2005 and 1 for the regulation period (2006–2010). 2. Control variables include the proportion of processing imports, import tariff rates, and the interaction term between the proportion of processing imports and import tariff rates. 3. Column (2) has fewer observations due to the exclusion of cases where the province of location could not be identified. 4. Robust standard errors, clustered at the product level, are reported in parentheses. ** $p < 0.05$.

Table A.3
Environmental effects of the regulation, 2006–2009: Based on heterogeneity analysis.

	Induced changes in emissions			
	China (1)	OECD (2)	non-OECD (3)	Global (4) = (1)+(2)+(3)
	A. Relative to the products with SO_2 intensity at the 25th quantile			
SO_x	−43,354	10,778	7926	−24,650
	(−44,537)	(14,973)	(7926)	(−24,650)
CO_2	−12,494	4905	3174	−4415
	(−13,087)	(5361)	(3174)	(−4552)
	B. Relative to the products with median SO_2 intensity			
SO_x	−9327	3145	1541	−4641
	(−9983)	(5477)	(1541)	(−2966)
CO_2	−3457	1363	710	−1383
	(−3788)	(1618)	(710)	(−1460)
	C. Relative to the products with SO_2 intensity at the 75th quantile			
SO_x	−2425	1047	454	−924
	(−2795)	(2367)	(454)	(27)
CO_2	−946	404	243	−299
	(−1134)	(548)	(243)	(−343)

Notes: 1. This table shows the results from calculating the environmental impacts of the regulation. We use heterogeneity estimates about the effects of regulation on imports. See Section 6.4 in the text for details. 2. Column (4) = (1)+(2)+(3). 3. SO_x in metric tons and CO_2 in thousand metric tons. 4. The numbers in parentheses are results from the calculations that include the 35 abnormal products from Australia. 5. An intermediate product with SO_2 intensity near the 25th quantile is "Polypropylene" (HS 6-digit code: 390210). Its total import value from 2006 to 2010 was 26 billion US dollars. Other products with the same SO_2 intensity include "Polyethylene having a specific gravity of 0.94 or more" (390120) and "acrylonitrile-butadiene-styrene copolymers (ABS)" (390330). An intermediate product with SO_2 intensity near the 50th quantile is "iron ores and concentrates, non-agglomerated" (HS 6-digit code: 260111). Its total import value from 2006 to 2010 was 82.8 billion US dollars. Other products with the same SO_2 intensity include "Copper ores and concentrates" (HS 6-digit code: 260300) and "iron ores and concentrates, agglomerated" (260112), etc. An intermediate product with SO_2 intensity near the 75th quantile is "terephthalic acid and its salts" (291736). Its total import value from 2006 to 2010 was 22.8 billion US dollars. Other products with the same SO_2 intensity include "Styrene" (290250) and "p-Xylene" (HS 6-digit code: 290243), etc. 6. Data for calculating country-industry emission intensity are not available for 2010 and beyond.

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