EU air pollution regulation: A breath of fresh air for Eastern European polluting industries?*

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Abstract

Does air quality regulation in the European Union (EU) foster polluting activity in emerging and developing countries? In this paper, we propose an original variable that evaluates regulation stringency, based on the EU Air Quality Framework Directive. Focusing on the underlying mechanism and controlling for endogeneity in the relation between regulation and trade, we provide robust evidence that EU countries implementing more stringent air pollution regulations import relatively more in pollution-intensive sectors from developing and emerging countries in Europe and Central Asia.

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Keywords: Air Pollution, Environmental Regulation, Trade

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1 Introduction

Global climate warming and pollution-related effects on human health have placed air pollution at the heart of policy decision-making. In recent estimates, the World Health Organization (WHO) reports that approximately 7 million people died as a result of air pollution in 2012 (one in eight of all deaths globally). Therefore, as emphasized by the organization, air pollution is now the world's largest single environmental health risk. Developed countries, particularly the European Union (EU) and the United States, have implemented strict regulations to improve air quality, while developing countries are generally characterized by weaker environmental regulations. This raises a central question: Has environmental stringency exacerbated air pollution problems in emerging and developing countries? In the current context of deeper trade and capital liberalization and the rapid dismantling of conventional trade barriers, air pollution regulation in developed countries could have increased the incentive to concentrate polluting activity in emerging economies. To gain some perspective on this issue, we focus on the effect of EU air pollution regulation on exports of countries from Eastern Europe and Central Asia (ECA).

Air pollution is indeed a major issue in ECA countries. Current environmental challenges originating from the historical legacy of the centrally planned economy are accentuated by low energy efficiency and weak environmental legislation (Bagayev and Najman, 2014, OECD, 2007). Many of the region's countries are among the most carbon-intensive exporters in the world (Davis and Caldeira, 2010).[1] The EU is the main trading partner of these countries. As a result of regulations, air quality has considerably improved in the EU, whereas it has at best stagnated or even strongly deteriorated in ECA countries. Despite ECA countries' small 8 percent share of European GDP (including Central Asia), carbon dioxide emissions (CO2) currently account for some 40 percent of total emissions in this region.[2] The contribution of ECA countries to European emissions has also greatly increased since the mid-1990s. The share of sulphur dioxide (SO2), another major pollutant, reached more than 50% in 2008 (see Figure 1).

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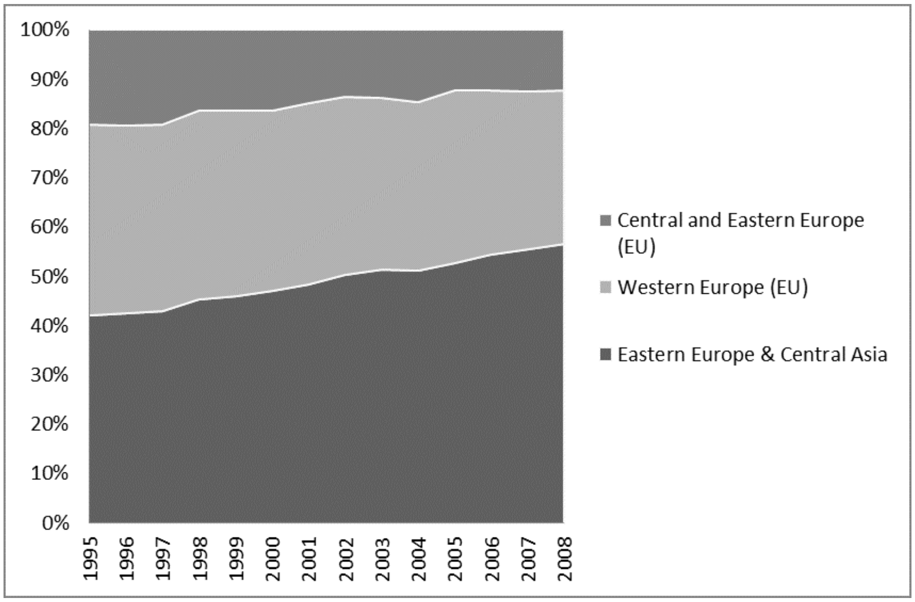
[1] Ukraine, Russia and Kazakhstan are the first, third and fourth leading carbon-intensive exporters worldwide, respectively.

[2] Data for 2010 come from the World Bank (World Development Indicators).

Figure 1: Sulphur dioxide (SO2) emissions in Europe and Central Asia (%)



Source: Emissions Database for Global Atmospheric Research (EDGAR).

In this paper we propose an original variable that evaluates air pollution regulation stringency. This variable is based on the Air Quality Framework Directive (AQFD) implemented by the EU in 1996. Its successive 'daughter' directives set numerical limits and thresholds for different types of pollutants and force countries to implement environmental measures in case of exceedance. The 1996 Framework Directive and its daughter directives are the main EU regulatory tools to fight air pollution in EU Member States. We construct an original variable that identifies, for every country and year, exceedance of air quality limit values and reflects tougher environmental regulation. In a similar fashion, several papers have examined the consequences of the U.S. Clean Air Act.[3] For instance, Becker and Henderson (2000) use the county non-attainment status as a proxy for stricter regulation and find that regulation reduces the creation of new firms in polluting industries, inducing a reallocation of stock of plants within the U.S. from non-attainment areas toward attainment areas (see also Greenstone, 2002). Hanna (2010) shows that U.S. multinationals also

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[3] The U.S. Clean Air Act establishes air quality standards that apply to every county in the U.S. Each year, every county is classified as being in or out of attainment (i.e., meeting or not meeting these standards) and non-attainment counties are required to submit a plan imposing more stringent regulation.

relocate outside the U.S. because of more stringent regulation. But these papers focus on firms' location and do not provide evidence of an increased polluting activity in emerging or developing countries due to tighter environmental regulation.

We contribute to the literature by showing that air pollution regulation in developed countries fosters polluting activity in emerging countries through larger exports in polluting sectors. Indeed, the related theoretical literature on pollution haven effects posits that countries with weak environmental regulations attract polluting industries from countries with more stringent regulations (see Copeland and Taylor, 2004). However, despite general opinion, cross-country econometric studies have typically found no effect of developed countries' environmental regulations on emerging countries' specialization in polluting industries.

It is now generally acknowledge that empirical studies testing for the impact of environmental regulation face several conceptual and methodological problems (e.g. Ederington et al., 2005, Levinson and Taylor, 2008, Brunel and Levinson, 2013). First, it is difficult to find an appropriate measure of regulatory stringency. Authors generally use either private sector abatement costs, indices based on surveys, measures of pollution, or public environmental expenditures. However, none of these measures is totally satisfactory, notably because all these measures capture only partially the multidimensional aspect of environmental regulation (Brunel and Levinson, 2013). Second, economic activity and environmental regulation may be determined simultaneously. The location of firms or international trade may influence regulators and lead them to establish more or less stringent rules. Third, omitted factors could influence both regulatory stringency and economic activity. Simultaneity and omitted variables lead to an endogeneity bias in the relation between environmental regulation and international trade or foreign direct investments. More recent studies attempting to tackle these methodological problems using panels of data and controlling for unobserved industry and country characteristics have demonstrated small but statistically significant environmental regulation effects (e.g. Broner et al., 2012).

Our approach tempers these methodological issues. First, our variable of air pollution regulation partially solves the simultaneity problem because air quality limit values are the same for all Member States and are based on the WHO guidelines to protect human health. Therefore, they do not respond to the level of trade.[4] Second, we test for the effect of environmental measures by examining the underlying mechanism: whether pollution-intensive goods are imported disproportionately more in countries enforcing additional air pollution regulations. Focusing on this conditional effect of environmental policy allows us to include a wide range of fixed effects to control for omitted variables. Third, considering the Air Quality Framework allows us to account for the multidimensions of environmental regulation because countries might implement any policy or measure in the case of exceedance of air quality limit values. However, the latitude granted to countries may be a source of endogeneity. Therefore, we also implement an instrumental variable approach to investigate the impact of air quality regulations on trade. Our instrumentation strategy based on Broner et al. (2012) consists of using exogenous variation in exceedances of limit values (our proxy for tougher regulation) related to meteorological characteristics. More explicitly, for every EU country, we compute an annual ventilation coefficient measuring the speed at which pollutants disperse in the air, and we use this variable as an instrument for the exceedance of limit values.

Using bilateral trade data for 27 EU importing countries and 11 Eastern European exporting countries over the 1999-2012 period, we find that more stringent air pollution regulations in EU countries increase their imports from ECA countries relatively more in sectors with high pollution intensity. Our results are supported by a number of robustness checks and a falsification exercise, where we find no regulation effect when we consider polluting countries that are below but close to the maximum level of emissions permitted by the AQFD (so that they do not have to enforce additional regulation). Moreover, we show that the effect of tougher environmental regulation prevails in the case of the 'old' EU-15 member states, where EU air quality regulations are likely to be implemented more effectively, and in the later period (after 2005). We also find that our main conclusions are robust to endogeneity issues. Overall, these results provide robust evidence that EU air quality regulation fosters polluting export activity in ECA countries.

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[4] Furthermore, because ECA countries represent only a small share of EU total trade, we believe that EU authorities will not enact a regulation depending on the level of trade with ECA countries.

The paper is structured as follows. In Section 2, we present the EU air quality framework. In Section 3, we describe our empirical strategy and data. In Section 4, we present our empirical results and in Section 5, we discuss endogeneity issues. In Section 6 we add some conclusions.

2 EU Air Quality Framework

Air quality has been a major issue in Europe since the early 1970s. In 1996, the EU adopted a series of ambitious actions to further decrease pollutant emissions throughout the continent. The most important was the setting of air quality binding targets and the implementation of a harmonised structure for monitoring, reporting and managing air quality across the EU through the 1996 AQFD and its daughter directives. These daughter directives set limit values and alert thresholds for the most prevalent air pollutants in order to better protect human health. For example, in the first daughter directive (1999/30/EC), limit values were established for sulphur dioxide (SO2), nitrogen oxides (NOx), lead and particulates (PM) (further pollutants, such as carbon monoxide, benzene or ozone were appended in subsequent daughter directives) (see Table A.1 in Appendix).

For the purposes of air quality assessment and monitoring, Member States have to define geographical areas within their territories. These zones include all agglomerations with a population of 250,000 inhabitants or more. Member States have full competence to define geographical limits of other zones on the basis of air quality management considerations, but they generally use administrative boundaries (European Commission, 2005).

The AQFD requires Member States to draw up detailed plans and programs for zones in which at least one pollutant exceeds its limit value plus the margin of tolerance in order to fall below the limit value.[5] The AQFD planning requirements -– in addition to

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[5] The first daughter directive entered into force in 1999, but, for each pollutant, there is a specific date by which limit values have to be met (for example, 2005 for SO2). In the runup to the attainment date, if the concentration of that pollutant is above the limit value plus a defined margin of tolerance, Member States must draw up plans "to demonstrate which measures they are going to take to achieve the limit values by the attainment date" (European Commission, 2005). The margin of tolerance decreases over time and must be equal to zero by the attainment date.

information related to the nature and origins of non-attainment and its location -– include the description of measures and programs implemented to improve air quality in these zones.

Two types of programs can be identified. Article 8(3) of the AQFD requires Member States to develop plans and programs in potential non-attainment zones, setting specific measures for meeting limit values within a time limit. These measures may be identified as medium- or long-term measures because they often require private long-standing investments, legal regulations, urban transport facility programs or long-term public investments. According to article 7, short-run measures must also be implemented in the case of exceedance of alert thresholds or limit values or when exceedance is anticipated for any given pollutant. Such measures include suspensions or restrictions of polluting activities contributing to the non-attainment or any other responsive actions able to be implemented quickly by the local competent authorities. For instance, the French annual reporting on air quality limit values plans in 2005 provides several short-term actions, such as traffic restrictions, requirements concerning industrial dedusting facilities, prescriptions to use high-pollutant fuels in industry, restrictions or the interruption of high-emitting production processes, etc.[6]

According to article 9, there are no particular requirements for Member States in zones where the levels of pollutant concentration are lower than the limit values or within the margin of tolerance.

An important characteristic of the AQFD is that limit values are legally binding, meaning that judicial actions may be undertaken if a Member State fails to comply with limit values. Moreover, the European Commission oversees the implementation of EU legislation and can launch legal proceedings, including enforcement measures against Member States that do

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[6] The French report for 2005 is accessible from http://cdr.eionet.europa.eu/fr/eu/aqpp/envr2ss9q/. When available, reports for other EU countries may be found through the Central Data Repository website (http://cdr.eionet.europa.eu/). More recently, in March 2014, France and, to a lower extent, Belgium and Germany experienced an extended episode of high air pollution particulates due to calm weather. The French Ministry of Ecology immediately announced a series of measures to reduce short-term pollution levels, such as free public transport in Paris, the reduction of tariff speed limits in some areas, controls of fertilizer spreading, etc.

not comply with the AQFD requirements.[7] From 2006 to 2012, the European Commission brought 420 environmental infringements concerning air quality issues to the European Court of Justice.[8] Measures to encourage or enforce compliance also rely on peer pressure and pressure from citizens and environmental organisations because the directives require Member States to inform the public about the assessment and management of air quality.

The AQFD is considered relatively effective in comparison with other environmental measures. According to a questionnaire sent to 90 stakeholders, this regulation has had a significant impact on improving air quality and reducing emissions and is viewed as one of the most cost-effective measures compared to other directives that focus more specifically on large combustion or industrial plants (Goldenman and Levina, 2004).

Measures that have to be implemented in order to meet limit values are different depending on the pollutant. In particular, they may be more or less expensive for the private sector and more or less constraining for industrial activity. According to a report addressed to the European Commission (EEA, 2006), the highest share of expenses implied by the EU environmental law in 2000 originates from SO2 controls. The main sources of sulphur oxides (SOx) emissions[9] are the energy sector and the manufacturing sector (accounting for 60% and 24% of EU-28 emissions in 2012, respectively) (EEA, 2014). Therefore, when emissions exceed the SO2 limit values, stringency measures included in national plans or programs target mostly the industrial sector.[10] In addition, emissions of this pollutant have experienced the largest decrease over the past fifteen years in the EU (see Figure 2). Total SOx emissions in 2012 were 64% less than in 1999. This may suggest that appropriate measures have been implemented in EU countries to reduce emissions of this pollutant. For all these reasons, we focus primarily on exceedances of SO2 limit values as a proxy for changes in environmental stringency affecting the industrial sector.

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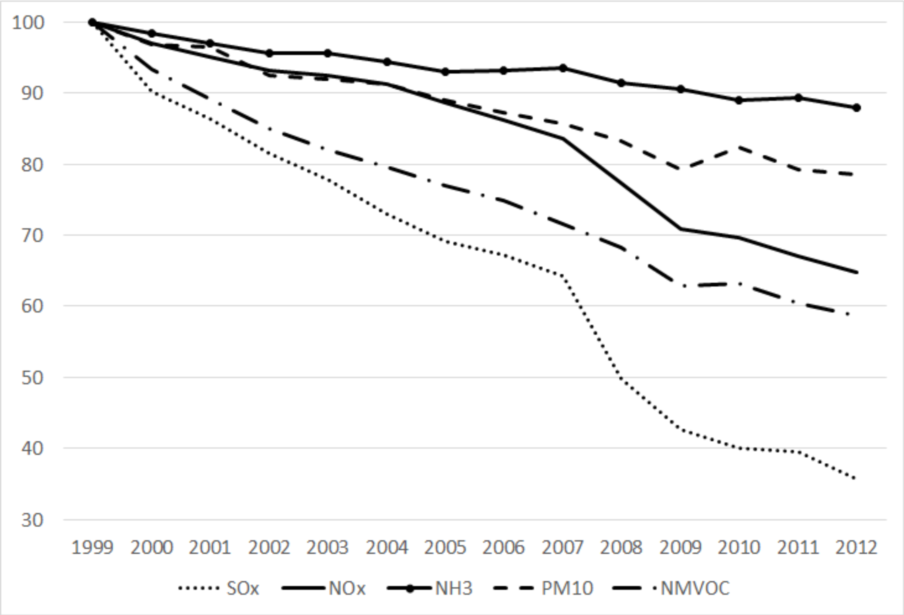
[7] This power of enforcement is not specific to air quality regulation but applies to all areas of EU law.

[8] Among these 420 infringements, less than 15% failed to comply with the judgment of the Court. Therefore, in 85% of all cases, Member States have fulfilled their obligations to comply with EU air quality regulations.

[9] SOx is a family of gases that includes SO2 and SO3. But the major part of emissions of sulphur oxides to the atmosphere is in the form of SO2.

[10] For other pollutants, stringency measures target uniformly all activities or, more specifically, the agricultural sector, households or road traffic. For example, exceedances of the limit value of nitrogen dioxide (NO2) might entail measures targeting mainly the primary NO2 emitter, i.e., road transport, responsible for approximately 50 percent of total emissions.

Figure 2: Variation in EU 28 emissions of SOx, NOx, NH3, PM10, and NMVOC (index, % 1999)



Source: EEA (Air Pollutant Emissions Data Viewer - LRTAP Convention).

More precisely, we construct an original variable (RegAQ) that measures, with a dummy variable, exceedances of SO2 hourly limit values (350 μg/m3) whenever the number of exceedances is larger than twenty four (which is the number allowed each year) and zero otherwise. In our empirical estimations, we also use another variable that counts for every country and year the number of exceedances whenever this number is larger than twenty four (see Tables A.1 and A.2 in Appendix). These variables do not aim to measure the overall level of environmental policy stringency, but rather *additional* environmental regulations implemented by EU countries to comply with the AQFD.

On our period of investigation (1999-2012), 12 countries have at least one exceedance of the SO2 hourly limit value (including both old and new EU member countries) and, thus, should have implemented further environmental measures to comply with air quality regulations. The average number of exceedances is 1.38 and is decreasing over time (see Figure 3).[11]

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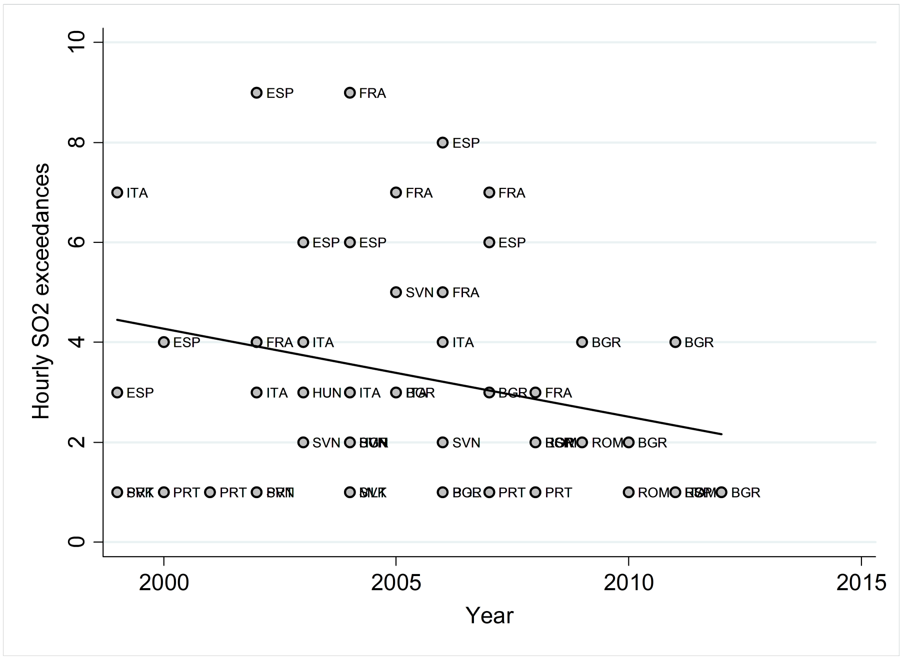
[11] Note that we exclude four country-year observations where the number of exceedances is larger than ten. These observations are clear outliers and concern Spain (2001 and 2005) and France (2001 and 2003).

Figure 3: Number of exceedances (strictly positive) of SO2 hourly limit value by country



Sources: AirBase database (EEA) and authors' calculations.

In the next section, we present the empirical strategy used to investigate the effect of the Air Quality Framework on EU imports from ECA countries and discuss some estimation issues.

3 Empirical model and data

3.1 Empirical strategy

We use a gravity model to investigate the role of air quality regulation on bilateral trade. The gravity model relates bilateral trade M_{ijst}, (e.g., imports) between country i and country j in sector s at time t to their economic sizes (Y_{it} and Y_{jt}), bilateral trade costs (τ_{ijt}) and multilateral trade resistance (P_{it} and P_{jt})(Anderson and van Wincoop, 2003).

The gravity equation can be written as:

$$M_{ijst} = \frac{Y_{it}Y_{jt}}{Y_{wt}}(\frac{\tau_{ijt}}{P_{it}P_{jt}})^{1-\sigma} \tag{1}$$

where Y_{wt} is the nominal world income and $\sigma > 1$ the elasticity of substitution between all goods. Trade costs (τ_{ijt}) are generally modelled as a function of some observable factors, including bilateral distance between trade partners, the existence of a common border, a common language, and regional trade agreements (RTA).

Multilateral resistance indices account for the fact that "the more resistant to trade with all others a region is, the more it is pushed to trade with a given bilateral partner" (Anderson and van Wincoop, 2003). A standard way to control for time-varying unobservable multilateral resistance terms is to use country-year (or country-sector-year) fixed effects (e.g. Baldwin and Taglioni, 2006). In our specification, country-sector-year fixed effects capture multilateral resistance indices and all other determinants of trade specific to a country, sector and year (such as economic size and all aspects of comparative advantage).

In this general model of trade, we introduce regulation in the importing country i. More precisely, we add an interaction term between an exporter country-industry characteristic (sector pollution intensity) and an importer country characteristic (air quality regulation) ($RegAQ_{it} \times Ener_{js}$) to the estimated equation. We expect that a more stringent environmental regulation will favour imports relatively more in sectors with high pollution intensity. This kind of interaction between an industry and a country characteristic was first used by Rajan and Zingales (1998), who show that industrial sectors that are more dependent on external finance grow more quickly in countries with a high level of financial development (see also Beck, 2003; or Nunn, 2007 for applications to trade). This approach provides a strong test of causality and allows us to introduce a wide range of fixed effect controls. Our estimated equation is as follows:

$$\begin{aligned} \ln M_{ijst} &= \beta_0 + \beta_1 \ln Dist_{ij} + \beta_2 Contig_{ij} + \beta_3 RegAQ_{it} \times Ener_{js} \\ &+ \alpha_{ist} + \alpha_{jst} + \epsilon_{ijst} \end{aligned} \tag{2}$$

where M_{ijst} are imports of country i from country j in sector s at time t, $Dist_{ij}$ is bilateral distance between countries i and j, and $Contig_{ij}$ is a dummy variable indicating that i and j share a border.[12] $RegAQ_{it}$ is our environmental regulation proxy (see Section 2), and $Ener_{js}$ is a proxy for sector pollution intensity (see Section 3.3). α_{ist} and α_{jst} are country-sector-year fixed effects, and ϵ_{ijst} is the usual error term. Our coefficient of interest is β_3, and we expect $\beta_3 > 0$ if a stricter regulation in European countries disproportionately increases their imports from ECA countries in sectors with high pollution intensity. This implies, for instance, that European countries with tougher environmental regulations would import relatively more chemicals (a pollution-intensive sector) than wood products.

We consider the bilateral imports of 27 EU countries from 11 countries in Europe and Central Asia over the 1999-2012 period.[13] All variables and data sources are described in Appendix (Table A.2).

3.2 Estimation issues

The measurement of environmental regulatory stringency is a fundamental issue in the empirical literature dealing with pollution havens. As highlighted by Levinson and Taylor (2008) and Brunel and Levinson (2013), empirical studies assessing the impact of environmental regulation face several conceptual obstacles. Our proxy variable for environmental regulation based on exceedances of air quality limit values allows us to tackle two major problems, i.e., simultaneity and multidimensionality.

First, the choice of our environmental regulation proxy attempts to address the simultaneity problem. The ambient air quality limits we consider are equally and uniformly imposed on all EU countries and are based on considerations related to the protection of human health. Thus, all Member States face the same limits of air quality pollutants, which are exogenous to their own economic activity or preferences (lobbying from citizens or industrial

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[12] We do not include a dummy variable for common language as in traditional gravity equations because of its low variation relative to our specific dataset. For the same reason, we omit the dummy for former colonial ties.

[13] These countries are Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, FYR Macedonia, Moldova, Russian Federation, Tajikistan and Ukraine.

sectors). As detailed in Section 2, exceedance of these thresholds imposes Member States to implement short-term and mid-term measures to meet the limit values. Therefore, the AQFD could be viewed as a quasi-natural experiment. Indeed, this directive requires countries to set up further measures or regulations to meet the limit values in zones with exceedances (the 'treatment' group). In contrast, countries are exempt from enforcing new environmental stringency measures when zones are below the limit values (the 'control' group).

The second obstacle to identifying the impact of environmental regulation is related to multidimensionality because it is difficult to capture this regulation with one single variable (Brunel and Levinson, 2013). In this paper, we do not focus on one particular measure, such as the lead content of gasoline or eco-taxation. Indeed, Member States have high flexibility in implementing adequate measures to reduce emissions below the limits imposed by the directives. Member States generally use multiple measures: setting up control devices to restrict polluting activities (for example, traffic restrictions or temporary shutdowns of polluting production processes) or impose obligations to use less-polluting inputs or technologies (see Section 2). However, the latitude given to countries in choosing the measures to be implemented could be a source of endogeneity. Countries with large polluting sectors can be tempted, in the case of exceedance, to implement measures that less heavily affect the most-polluting industries. We control for this potential endogeneity issue by using an instrumental variable approach (see Section 5).

Note that, in our regressions, the level of emissions (and the global stringency of the environmental regulation) in every country is controlled for using country-sector-year fixed effects. Therefore, our variable of interest (exceedances of limit values) measures *additional* regulations implemented to comply with the AQFD. In robustness checks, we further control for the level of emissions in each country and sector (see subsection 4.2).

3.3 Proxy for sector pollution intensity

For the purpose of our empirical strategy, we need information about structural air pollution intensity varying over countries and sectors ($Ener_{js}$ in equation 2). The empirical literature dealing with the pollution haven effect generally uses proxies that vary only across sectors and that identify dirty industries. Typically based on U.S. sector data, industries are ranked according to their toxicity (emission intensity for one or all pollutants) and then classified as "dirty" or "clean" using a dummy variable (Copeland and Taylor, 2004). Allowing the pollution intensity proxy to vary across sectors and *countries* should better capture the differences in comparative advantage in polluting industries. Moreover, our empirical strategy needs a pollution intensity indicator with sufficiently high variability to ensure that the interaction term $RegAQ_{it} \times Ener_{js}$ will not be captured by the set of fixed effects included in equation (2).

We use *exporter* (ECA) country pollution intensity because it is exogenous to the importer's environmental policy and should be related to the dependent variable only through the pollution haven effect mechanism. In contrast, *importer* (EU) country pollution intensity may be endogenous to trade via intra-industry imports of pollution-intensive inputs (upward bias). Instead, if pollution-intensive imports substitute local production, the share of polluting sub-sectors in the importer country should decrease, thus decreasing sector pollution intensity (downward bias). This composition effect has been highlighted by Copeland and Taylor (2004) and Levinson and Taylor (2008). To avoid this endogeneity and composition biases, we use the pollution intensity proxy reported by the *exporter* (ECA) country. For robustness, we also report results using a more conventional proxy varying only at the sector level and computed using U.S. sector data.

Data on industry pollution intensity is typically not available for most ECA countries. One way to address this problem is to find a proxy for air pollution at the industry level. Energy consumption data provided by the International Energy Agency seem appropriate. There is a strong statistical relationship between firm- or industry-level energy use and air pollution in developed countries (see Eskeland and Harrison, 2003; Cole et al., 2005). We expect an even stronger correlation in our sample, as emission control equipment is likely to be less constraining and the air pollutant content of fuels higher than in developed countries.

Energy combustion processes are the main anthropogenic emitters of SO2: combustion in manufacturing and energy industries, as well as production processes, account for approximately four-fifths of SO2 emissions (EEA, 2014). Therefore, energy-intensive industrial sectors are likely to be the most affected by measures involved with exceedances of SO2 limit values. Focusing on the interaction of SO2 exceedances with sector energy intensity should provide an accurate identification strategy to test our empirical question.

We match data on energy use (in kilotons of oil equivalent) from the International Energy Agency (IEA) with sector value added (in 2000-constant USD) from the United Nations Industrial Development Organization (UNIDO). We are thus able to define energy intensities at the 2-digit industrial level for 11 ECA countries.[14] As we only need the technological content of energy use by industry and country, we compute country-industry energy intensities for the year 2007, which provides the highest data accuracy.[15] Moreover, keeping the energy intensity constant prevents our variable from being affected by sub-sector activity shifts and efficiency improvements.[16]

Because of missing or inaccurate data, we have 85 sector-country energy intensities out of a total of 110 possible cases (10 manufacturing sectors in 11 exporting countries). Table 1 displays summary statistics and the ranking of energy-intensive industries across exporting countries. An important feature is that leading energy-intensive sectors (iron and steel, non-metallic minerals, non-ferrous metals, chemicals and paper, pulp and print) are the same as those defined as dirty industries in the pollution haven literature (see, for example, Mani and Wheeler, 1998). The most energy-intensive sectors are particularly aligned to the main conventional air pollutant emitters (Greenstone, 2002, Cole et al., 2005). Moreover, as shown in Cole et al. (2005), the correlation between energy use and air pollution is the highest for SO2 emissions.

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[14] IEA energy consumption data and UNIDO value added data are not displayed in the same classification, respectively, 2-digit ISIC rev.4 and 3-digit ISIC rev.3. We match both data types using the correspondence table from the UNIDO website. When matching was imperfect or unclear, we consider data as missing for the corresponding sectors. The manufacture of rubber and plastics products is missing from our data for this reason.

[15] We use the year 2008 to compute energy intensity for Belarus because of data unavailability for 2007.

[16] Changing the reference year or allowing energy intensities to vary over time would not fundamentally alter our results but would affect the size of our sample.

Table 1: Energy intensity in ECA countries by sector (2007)

2-digit industrial sectors	Rank	Mean	Std. Dev.
Iron and steel	1	0.20	0.22
Non-metallic minerals	2	0.13	0.05
Non-ferrous metals	3	0.11	0.14
Chemicals	4	0.08	0.08
Paper, pulp and print	5	0.04	0.05
Wood and wood products	6	0.04	0.02
Food and tobacco	7	0.02	0.01
Textile and leather	8	0.02	0.01
Transport equipment	9	0.02	0.02
Machinery	10	0.01	0.01

Notes: Energy intensity is defined as energy consumption in kilotonnes of oil equivalent per value added in PPP 2011 dollars. Sources: IEA, UNIDO, authors' calculations.

4 Empirical results

4.1 Overall results

We begin by reporting OLS estimates of the conditional impact of environmental stringency on EU imports from ECA countries. Table 2 provides results of the estimation of our basic specification (equation 2). Conventional gravity variables (distance and contiguity) are significant and display the expected signs. A larger distance deters bilateral trade, while countries sharing a border trade more, all else being equal. The specification controls for country-sector-year fixed effects that take into account potential omitted factors and sources of comparative advantage. To capture a change in environmental regulation, we first introduce a dummy variable indicating whether SO2 emissions exceed the limit value in a given country and a given year (see Section 2). The interaction between this dummy variable and energy intensity at the country-sector level thus captures the *differential* impact of additional air pollution regulation depending on a sector's pollution intensity. The coefficient is positive and significantly different from zero at the 5 percent level (Column

Table 2: OLS estimations

	(1)	(2)
$RegAQ\ SO2h_{it}$ (dummy)$\times \ln Ener_{js}$	0.247**	
	(0.114)	
$RegAQ\ SO2h_{it}$ (number)$\times \ln Ener_{js}$		0.0518**
		(0.0230)
Distance$_{ij}$ (ln)	-2.267***	-2.265***
	(0.282)	(0.283)
Contiguity$_{ij}$	0.738***	0.737***
	(0.273)	(0.274)
Constant	25.97***	25.96***
	(2.162)	(2.167)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes
Observations	20,223	19,900
Adjusted R^2	0.732	0.732

Notes: The dependent variable is the logarithm of bilateral imports. The variable *RegAQ SO2h* (dummy) is a dummy variable equal to one if SO2 hourly emissions exceed the AQFD limit value. The variable *RegAQ SO2h* (number) indicates the number of exceedances of SO2 hourly limit value. $\ln Ener$ is sector energy intensity expressed as the logarithm of energy consumption over value added. Robust standard errors clustered by bilateral country-pair in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

1). This result strongly supports our testing assumption. The positive and significant sign of the interaction term indicates that more-regulated EU countries (i.e., countries implementing a more stringent regulation to comply with the AQFD) import relatively more in sectors with high pollution intensity from ECA countries. To get a sense of the magnitude of the coefficient, compare two around-median sectors in terms of energy intensity (chemicals and wood). Our estimation results imply that in countries implementing additional environmental regulation (in case of exceedance of the AQFD limit values) the increase of imports of chemicals is 25% higher than in the wood sector [=0.247*(1-0)*100].[17]

In Column 2, we measure environmental regulation by the number of exceedances of the SO2 hourly limit value in every country and year.[18] Here again, we find a positive and significant coefficient for the interaction variable.

4.2 Sensitivity analysis

We further test the sensitivity and robustness of our results, first with respect to the energy intensity variable. In Columns 1 and 2 of Table 3, we exclude electricity consumption from total energy consumption. This leaves fossil energy, which is more likely to contribute to SO2 emissions. As previously, we interact this fossil energy intensity variable with the dummy equal to one in case of exceedance of limit values (Column 1) or the number of exceedances (Column 2).[19] The positive and significant coefficients for the interaction variables in Columns 1 and 2 show that more-regulated EU countries import relatively more in sectors that are more intensive in fossil energy. This estimation also indicates that our results are not driven by electricity consumption. Thereafter, we present only our estimation results with the interaction on the dummy variable.[20]

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[17] According to Table 1, energy intensity in the chemicals sector (0.08) is 100% higher than in the wood and wood products sector (0.04).

[18] In this estimation, we exclude four country-year observations for which the number of exceedances is larger than ten. We obtain very similar results when we include these outliers and a dummy variable that captures their specific behavior. Results are available upon request.

[19] Note that the sample is smaller than the benchmark (Columns 1 and 2 of Table 2) because of more missing observations for the fossil energy intensity variable.

[20] Results obtained with the number of exceedances (instead of the dummy) provide the same general conclusions and are available upon request.

Table 3: Robustness checks

	(1)	(2)	(3)	(4)	(5)
$RegAQ\ SO2h_{it}$ (dummy)$\times \ln Fossil\ Ener_{js}$	0.179*				
	(0.098)				
$RegAQ\ SO2h_{it}$ (number)$\times \ln Fossil\ Ener_{js}$		0.0486***			
		(0.0180)			
$RegAQ\ SO2h_{it}$ (dummy)$\times Ener_s^{US}$			0.336***		
			(0.122)		
$RegAQ\ SO2h_{it}$ (dummy)$\times \ln Ener_{js}$				0.235*	
				(0.132)	
SOx Emissions$_{it}$ (ln)$\times \ln Ener_{js}$				0.008	
				(0.041)	
$NonRegAQ\ SO2h_{it}$ (dummy)$\times \ln Ener_{js}$					0.133
					(0.102)
Distance$_{ij}$ (ln)	-2.308***	-2.296***	-1.446***	-2.257***	-2.476***
	(0.324)	(0.326)	(0.177)	(0.298)	(0.279)
Contiguity$_{ij}$	0.834***	0.837***	0.625***	0.742***	0.663**
	(0.296)	(0.296)	(0.139)	(0.276)	(0.261)
Constant	25.76***	25.66***	20.40***	25.96***	27.49***
	(2.457)	(2.464)	(1.601)	(2.360)	(2.173)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes	No	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes	No	Yes	No
Importer-year fixed effects$_{it}$	No	No	Yes	No	No
Exporter-year fixed effects$_{jt}$	No	No	Yes	No	No
Importer-sector (4-digit) fixed effects$_{is}$	No	No	Yes	No	No
Exporter-sector (4-digit) fixed effects$_{js}$	No	No	Yes	No	No
Observations	15,181	14,982	170,384	18,922	16,707
Adjusted R^2	0.740	0.740	0.606	0.733	0.734

Notes: The dependent variable is the logarithm of bilateral imports. The variable $RegAQ\ SO2h$ (dummy) is a dummy variable equal to one if SO2 hourly emissions exceed the AQFD limit value. The variable $RegAQ\ SO2h$ (number) indicates the number of exceedances of SO2 hourly limit value. $\ln Fossil\ Ener_{js}$ is sector fossil fuel energy intensity expressed as the logarithm of non-electric energy consumption over value added. $\ln Ener$ is sector energy intensity expressed as the logarithm of energy consumption over value added. $Ener_s^{US}$ is a normalized measure of sector energy intensity based on 4-digit U.S. manufacturing data (see Appendix for details). The variable $NonRegAQ\ SO2h$ (dummy) is a dummy variable equal to one if SO2 hourly emissions do not exceed the number of yearly exceedances allowed by the AQFD. Robust standard errors clustered by bilateral country-pair in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

In Column 3, we measure energy intensity in a more traditional way, at the sector level (instead of the country-sector level), using data from the U.S. More precisely, we compute a measure of structural energy intensity ($Ener_s^{US}$) over a 20-year period (1990-2009) based on energy cost information at the 4-digit sector level. A sector's structural energy intensity is given by its dummy coefficient in the estimation of energy cost intensity of U.S. manufacturing sectors. The variable is normalized between 0 and 1 (see Appendix for details). Note that the number of observations is greater than in previous estimations thanks to the higher disaggregation of sectors, but the range of fixed effects is constrained to country-year and country-sector (instead of country-sector-year). The coefficient for the interacted variable is still positive and significant and very close to the benchmark estimate (Column 1 of Table 2). In this case, the interpretation of the coefficient is more straightforward. Consider a sector characterized by the 75th percentile level of pollution intensity in our sample ('asphalt felts and coatings', $Ener_s^{US} = 0.455$). According to our estimates, if an EU country implements additional programs to comply with the AQFD, then its imports of asphalt felts and coatings from ECA countries would increase by 17% on average ($= exp(0.455 \times 0.336 \times (1 - 0)) - 1$).

In Column 4, we include as an additional control variable the level of SOx emissions interacted with energy intensity. This allows us to test whether our variable measuring exceedances of limit values is a good proxy for changes in environmental regulation and does not capture only the level of emissions. Note that, in this specification, the level of emissions is captured by country-sector-year fixed effects. For this reason, in Column 4, we add only the interaction between the level of emissions and our energy intensity variable. We find that this variable *per se* does not affect imports and that our interaction variable for environmental regulation remains large and significant at the 10% level.[21]

Last but not least, to test the robustness of our results, we exploit the discontinuity in the relationship between air pollution concentration and environmental regulation implied by the AQFD. As described in Section 2, countries belonging to the 'treatment' group

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[21] The less significant impact of our interaction variable is probably due to multicollinearity (a high correlation between the level of emissions and exceedances of limit values). Note that the value of the coefficient is very close to the benchmark estimate, but the standard error is larger.

according to the AQFD are countries exceeding the hourly 350 μg/m3 SO2 limit value *more than twenty four times in a year.* Thus, as a falsfication exercise, we consider the effect of SO2 hourly limit value violations whenever this number is *lower* than twenty four but positive. In this case, countries do not fall under the AQFD 'non-attainment' status and do not have to enforce additional specific regulations to decrease air pollution concentration. As reported in Column 5, the coefficient of the interaction term is not significant.[22] This provides further evidence of the threshold effect of the AQFD.[23] Countries seem to import more in pollution-intensive sectors only when they must implement new environmental measures to decrease their levels of air pollution concentration.

Then, in Table 4, we test for the environmental regulation effect over different sub-samples. We first drop one specific sector, iron and steel, from the dataset (Column 1). This sector is the most energy intensive (see Table 1) and uses a great deal of pollution-intensive inputs. In particular, the EU steel industry imports a large share of its iron and low-quality steel inputs from ECA countries. This could be a source of an upward bias in the OLS estimates if imports of pollution-intensive inputs increase the production of pollution-intensive goods and, thus, contribute to exceedances of the SO2 limit value. It could also produce a downward bias if increasing environmental stringency limits the activity of the iron and steel industry and decreases the need to import highly pollution-intensive intermediate inputs from ECA region. When we exclude iron and steel from the analysis (Column 1), the $RegAQ\ SO2h_{it}$ interaction variable is still positive and significant. The magnitude of the coefficient is similar to the benchmark coefficient (Column 1 of Table 2), indicating that the bias is not so large or that we have both an upward and a downward bias.[24]

In Columns 2 and 3, we estimate our basic model for two sub-samples. In Column 2, we restrict the sample to the EU-15 countries, and in Column 3, we restrict the sample

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[22] For sake of comparison, we have excluded from the estimation country-year observations reporting exceedances of the SO2 limit values. This explains the lower number of observations in Column 5.

[23] In unreported regressions, we also test the robustness of our results by focusing on the hourly limit value (350 μg/m3). Similarly, we find no significant impact of the regulation when we consider countries that are below but close to the hourly limit value.

[24] We also estimate our model by dropping successively each of the other nine sectors and find, in all cases, a positive and significant coefficient for our variable of interest (comprehensive results are available upon request).

Table 4: OLS estimations over different sub-samples

	w/o Iron & Steel (1)	EU15 (2)	EU+12 (3)	≥2005 (4)	<2005 (5)
$RegAQ\ SO2h_{it}$ (dummy)×ln $Ener_{js}$	0.258**	0.262**	0.174	0.296**	0.169
	(0.122)	(0.130)	(0.164)	(0.141)	(0.130)
Distance$_{ij}$ (ln)	-2.251***	-2.341***	-2.354***	-2.351***	-2.085***
	(0.290)	(0.390)	(0.340)	(0.284)	(0.332)
Contiguity$_{ij}$	0.795***	1.217***	0.294	0.726***	0.759**
	(0.281)	(0.348)	(0.299)	(0.277)	(0.315)
Constant	25.86***	26.42***	32.20***	24.80***	24.74***
	(2.210)	(2.902)	(2.542)	(2.257)	(2.492)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes	Yes	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes	Yes	Yes	Yes
Observations	18,645	12,209	8,014	13,015	7,208
Adjusted R^2	0.732	0.746	0.741	0.730	0.738

Notes: The dependent variable is the logarithm of bilateral imports. The variable *RegAQ SO2h* (dummy) is a dummy variable equal to one if SO2 hourly emissions exceed the AQFD limit value. $\ln Ener$ is sector energy intensity expressed as the logarithm of energy consumption over value added. Robust standard errors clustered by bilateral country-pair in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

to new EU-comers (the ten Eastern European countries, Cyprus and Malta, EU+12).[25] Interestingly, our variable of interest is positive and significant only in the case of the EU-15 sub-sample. This indicates that the pollution haven effect seems to affect only imports of richer EU countries. This result is consistent with our expectations. Measures to comply with the EU air quality regulation are likely to be implemented more stringently in 'old' member states. Moreover, inter-sectoral factor mobility is probably larger in EU-15 countries so that an increase in the relative cost in pollution-intensive sectors may lead to a greater reallocation of production in these countries.

In Columns 4 and 5 of Table 4, we estimate our model for two sub-periods: before and after 2005. We expect a larger effect of environmental regulation on the later period. Indeed, the SO2 limit value (without any margin of tolerance) fully applies beginning in 2005, and the overall constraint to implement measures in order to meet the limit values should be more intense for all countries from that year. Column 4 shows the results of our baseline specification restricting the sample to the 2005-2012 sub-period. As expected, the magnitude of the interaction term coefficient is larger than in Column 1 of Table 2 and remains highly significant. Conversely, we do not find any impact of the Air Quality framework before 2005, which is reassuring (Column 5).

Finally, we test the robustness of our results with respect to the estimation method. Instead of the OLS estimator, we use a Poisson Pseudo-Maximum Likelihood (PPML) estimator. As highlighted in the recent literature, the PPML estimator has several advantages: it incorporates the zero trade values and is robust to different patterns of heteroskedasticity (e.g. Santos Silva and Tenreyro, 2006). We report these new estimation results in the Appendix (Table B.1). Note that, in this table, we restrict the number of fixed effects because the PPML estimator has trouble converging in the case of a very large number of fixed effects. We first report the simple OLS estimator, which drops the zero trade observations (Column 1). We then turn to the PPML estimator without and with the zero trade values (resp. Columns 2 and 3).[26] Results are consistent with our previous findings. In comparison with our baseline results controlling for country-sector-year fixed effects, the coefficient

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[25] Eight Eastern European countries, Cyprus and Malta joined the EU in 2004, and Romania and Bulgaria joined in 2007.

[26] Note that the UN Comtrade database reports only strictly positive trade flows. Therefore, to distin-

of the interaction term is lower (Column 1 vs. Column 1 of Table 2). Thus, country- and sector-specific demand and supply shocks seem to be potential sources of omitted variable bias, downwarding the estimated effect. PPML estimates are significant and close to the OLS results. The inclusion of zero trade data does not affect these estimates (Column 3 vs. Column 2), suggesting that heteroskedasticity is potentially more problematic than truncation, which is in line with the related literature using PPML (Santos Silva and Tenreyro, 2006).

Overall, our results support evidence that EU air quality regulation fosters pollution-intensive specialization of ECA countries.

4.3 Other pollutants

Table 5 presents regression results using five alternative proxies for environmental regulation related to exceedances of the limit values for SO2 (daily), PM10 and NO2. In the first column of Table 5, our measure of environmental stringency is captured by a dummy equal to one when a country exceeds the SO2 *daily* limit value (over 3 occurrences per year) allowed by the air quality directive. The impact of the interaction term is positive, significant and almost unchanged compared to our baseline estimation (Column 1, Table 2). This result confirms that the effect of environmental regulation due to exceedances of SO2 limit values is not sensitive to the change of our proxy variable (hourly or daily).

Aside from SO2 limit values, we further investigate the trade effect of environmental programs related to exceedances in two other main air pollutants, i.e., particulates (PM10) and nitrogen dioxide (NO2). For this purpose, we use three new dummies capturing exceedances in the daily PM10, yearly PM10, hourly NO2 and yearly NO2 concentrations. We compute these four dummy variables using air quality thresholds given in the first daughter directive (1999/30/EC) (see Table A.1 in Appendix). In Columns 2 and 3, we focus on daily and yearly limit values for PM10. Because polluting industries, captured by sector energy intensity, are also important emitters of PM10, we expect to find a positive

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guish between zero and missing trade values, we follow the usual assumption: we consider that a missing value is a zero when a country reports at least one positive trade flow for a given year in a given sector.

Table 5: Other pollutants

	(1)	(2)	(3)	(4)	(5)
$RegAQ\ SO2d_{it}$ (dummy)$\times \ln Ener_{js}$	0.228**				
	(0.105)				
$RegAQ\ PM10d_{it}$ (dummy)$\times \ln Ener_{js}$		0.0960			
		(0.119)			
$RegAQ\ PM10y_{it}$ (dummy)$\times \ln Ener_{js}$			0.198*		
			(0.101)		
$RegAQ\ NO2h_{it}$ (dummy)$\times \ln Ener_{js}$				0.0848	
				(0.0963)	
$RegAQ\ NO2y_{it}$ (dummy)$\times \ln Ener_{js}$					0.0593
					(0.142)
Distance$_{ij}$ (ln)	-2.253***	-2.249***	-2.253***	-2.276***	-2.247***
	(0.279)	(0.287)	(0.285)	(0.281)	(0.281)
Contiguity$_{ij}$	0.695**	0.720***	0.721***	0.707***	0.698***
	(0.273)	(0.275)	(0.274)	(0.271)	(0.272)
Constant	25.83***	25.24***	25.25***	25.81***	25.79***
	(2.139)	(2.224)	(2.216)	(2.152)	(2.245)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes	Yes	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes	Yes	Yes	Yes
Observations	20,897	20,197	20,197	20,673	20,897
Adjusted R^2	0.732	0.732	0.732	0.732	0.731

Notes: The dependent variable is the logarithm of bilateral imports. The variable $RegAQ\ SO2d_{it}$ (dummy) is a dummy variable equal to one if SO2 daily emissions exceed the AQFD limit value. The variables $RegAQ\ PM10d_{it}$ (dummy) and $RegAQ\ PM10y_{it}$ (dummy) capture exceedances of PM10 daily and yearly limit values. The variables $RegAQ\ NO2h_{it}$ (dummy) and $RegAQ\ NO2y_{it}$ (dummy) capture exceedances of NO2 hourly and yearly limit values. $\ln Ener$ is sector energy intensity expressed as the logarithm of energy consumption over value added. Robust standard errors clustered by bilateral country-pair in parentheses. *** p<0.01, ** p<0.05, * p<0.1

relationship between exceedances of PM10 limit values and imports in polluting sectors from ECA countries. The conditional effect related to exceedances of PM10 daily limit values is not significant (Column 2), which is probably due to the low variability of this dummy variable. The corresponding variable for the PM10 yearly threshold is positive and significant at the 10% level (Column 3).[27] The size of the impact is slightly smaller than our basic estimate (Column 1 of Table 2), indicating that the conditional effect of environmental regulation is larger in the case of S02 exceedances than for PM10 exceedances. This is consistent with the fact that measures implemented to meet PM10 limit values do not focus primarily on polluting industries but rather concern automotive traffic, dedusting facilities and the construction sector.[28] Another explanation may be related to our proxy for sector pollution generation (i.e., energy consumption), which could be more closely related to SO2 than to PM10 pollution (see Section 3.3).

Similarly, in the last two columns of Table 5, we look at the trade effect of environmental regulation related to exceedances of (hourly and yearly) NO2 limit values. We do not find any significant effect for the interaction terms in these cases, indicating that measures to meet NO2 air concentration thresholds do not increase imports relatively more in pollution-intensive sectors. Here again, this result is probably due to the specific measures implemented to comply with NO2 limit values. These measures are related mainly to the largest anthropogenic emitter of NO2 – road traffic (traffic restrictions, transport sector regulations, etc.) – and, thus, should affect manufacturing sectors independently of their pollution intensity.

Overall, results reported in Table 5 are consistent with our expectations and show that EU air quality standards impact imports of pollution-intensive sectors mainly through measures implemented to meet SO2 limit values and, to a lesser extent, through measures related to exceedances of the PM10 thresholds.

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[27] Exceedances of the PM10 daily limit value are very frequent. Over our period of investigation, countries do not meet limit values in almost 90% of all cases. The dummy variable identifying exceedances of the PM10 yearly limit value has a more normal distribution, with approximately 70% of exceedances.

[28] Trade flows in the construction sector are not available in our database. See Table 1 for the list of industrial sectors included in this paper.

5 Endogeneity and instrumental variable results

In the previous section, we show that more stringent air quality regulations in EU countries increase their imports from ECA countries relatively more in sectors with high pollution intensity. Despite our effort to limit endogeneity issues using country-sector-year fixed effects and an interaction variable, our results could still be affected by endogeneity. Polluting industry lobbying in strategic domestic sectors may influence the type of measures chosen by national authorities to meet the limit values, preventing the implementation of measures constraining polluting industrial activity (see Section 3.2). In this case, OLS estimates will be underestimated. Reverse causality may also introduce both a positive and a negative bias. It is possible that countries importing a great deal of pollution-intensive goods produce fewer of these goods, leading to a decrease in the number of exceedances (our proxy for environmental regulation). Conversely, in countries importing a great deal of inputs in sectors with high pollution intensity (e.g., iron and steel or chemicals), the production of pollution-intensive goods may increase, leading to an increase in the number of exceedances. In this case, OLS estimates will be overestimated. An endogeneity bias may also be due to measurement error in the environmental regulation proxy variable.

To overcome this endogeneity bias, we implement an instrumental variable (IV) methodology. Our instrumentation strategy relies on Broner et al. (2012). To instrument environmental regulation, we compute for every country and year a ventilation coefficient measuring the speed at which pollutants disperse in the air. Then, we interact this ventilation coefficient with our variable measuring sector pollution intensity.

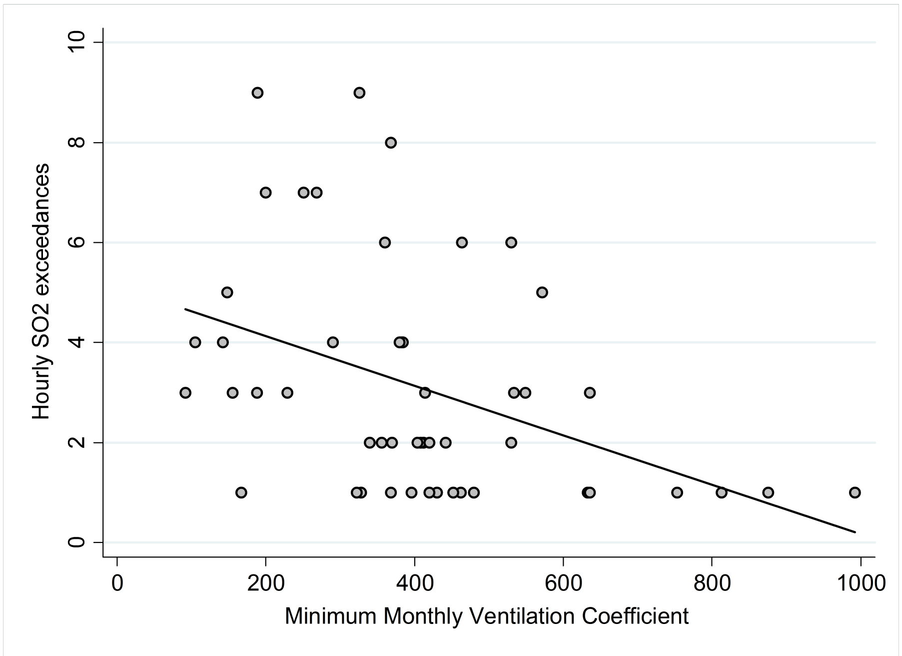
The ventilation coefficient is based on two meteorological processes: wind and the depth of the atmospheric mixed layer. Wind and mixing height are the main sources of air motion and contribute largely to the dispersion of air pollution in the atmosphere. By multiplying these two variables, we obtain a very simple ventilation coefficient for a given area. This information is commonly used in meteorological studies to assess and anticipate levels of pollution concentration in a given region. Monthly ERA-Interim data from the European Centre for Medium-Term Weather Forecasting (ECMWF) give ventilation coefficients for the whole European continent grid of 0.25° x 0.25° cells (representing on average less than 10 square kilometres). We merge data on the ventilation coefficient with geographical coordinates of all monitored stations used to assess air quality levels in each EU Member State. For every EU country and year, we use the minimum monthly ventilation coefficient to obtain country-annual observations.

There are fundamental differences between the IV strategy in Broner et al. (2012) and our strategy. Because Broner et al. (2012) aim to determine the countries' long-term comparative advantage in polluting activities, they average monthly ventilation coefficients over the 1980-2010 period for capital cities throughout the world. In comparison, our aim is to capture the trade effect of a change in environmental regulation in EU countries. Because stringency measures implied by the AQFD rely on short-term (hourly, daily and yearly) air pollutant concentrations, we need air ventilation coefficients that vary across time. Therefore, we first compute a monthly series of ventilation coefficients for all areas in which stations used to identify compliance with air pollution limit values are located; then, we use the minimum monthly ventilation coefficient for each country and year.

A good instrument satisfies two conditions: (i) it is relevant for explaining exceedances of the AQFD limit values and (ii) it is uncorrelated with the error term (ϵ_{ijst} in equation 2). Our ventilation coefficient seems to satisfy the first condition. As apparent in Figure 4, there is a strong negative correlation between our instrumental variable and exceedances of hourly SO2 limit values. An increase of the minimum monthly ventilation improves the ability to disperse air pollutant concentration and, thus, decreases the probability of exceeding the AQFD limit values.

Then, in order to satisfy the exclusion restriction, local and short-term weather conditions must be exogenous in equation (2). The correlation between our instrumental variable and important climate events may lead to the violation of this restriction. Indeed, large-scale climate events could arguably affect trade patterns through channels other than environmental regulation. In particular, periods of extreme cold or heat waves can influence input or trade costs and, thus, competitiveness. However, country-sector-year fixed effects should account for these climate events. Change of input prices (e.g., oil prices) related to climate

Figure 4: Number of SO2 exceedances of the hourly limit value and ventilation coefficient



Sources: AirBase database (EEA), ERA-Interim data (ECMWF) and authors' calculations.

shocks should evenly affect regulated and unregulated countries. Similarly, the change in trade costs should affect tradable sectors independently of their energy intensity. Finally, a potential reverse causality bias may arise if local air ventilation is negatively linked to cold local temperatures. Local cold periods might increase both the probability to exceed air pollution concentration and the energy bill, thus affecting industry competitiveness, particularly that of energy-intensive sectors. To the best of our knowledge, there is no scientific evidence of such a negative relationship between cold temperatures and air ventilation. In contrast, low air ventilation is more often associated with warm ground-level temperatures, for example, in the case of the inversion layer (leading to smog in urban areas).

Estimation results using the IV approach are displayed in Table 6. The bottom row of the table corresponds to the first-stage estimation and shows that our instrumental variable, the interaction between the ventilation coefficient and sector energy intensity, has a highly significant effect on the exceedance of the SO2 limit value (interacted with energy intensity). As expected, the effect is negative. This supports the simple correlation illustrated

Table 6: 2SLS estimations

2nd stage Instrument: Minimum Monthly Ventilation Coefficient$_{it}$ (ln)×ln $Ener_{js}$	(1)	(2)
$RegAQ\ SO2h_{it}$ (dummy)×ln $Ener_{js}$	0.724**	
	(0.317)	
$RegAQ\ SO2h_{it}$ (number)×ln $Ener_{js}$		0.205***
		(0.079)
Distance$_{ij}$ (ln)	-2.261***	-2.258***
	(0.279)	(0.246)
Contiguity$_{ij}$	0.759***	0.759***
	(0.273)	(0.240)
Constant	25.88***	25.83***
	(2.150)	(1.886)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes
1st stage		
Dependent variable	$RegAQ$ $SO2h_{it}$ (dummy)× ln $Ener_{js}$ (1)	$RegAQ$ $SO2h_{it}$ (number)× ln $Ener_{js}$ (2)
Min. Monthly Ventilation Coeff.$_{it}$ (ln)×ln $Ener_{js}$	-0.250***	-0.922***
	(0.004)	(0.047)
Distance$_{ij}$ (ln)	-0.007	-0.044
	(0.009)	(0.040)
Contiguity$_{ij}$	-0.035***	-0.123***
	(0.010)	(0.032)
Constant	-4.04***	-14.62***
	(2.162)	(1.001)
Importer-sector-year fixed effects$_{ist}$	Yes	Yes
Exporter-sector-year fixed effects$_{jst}$	Yes	Yes
Observations	20,223	19,900
Partial R^2	0.1899	0.1539
F test of excluded instrument	191.18***	83.32***

Notes: The dependent variable in the 2nd stage estimation is the logarithm of bilateral imports. The variable *RegAQ SO2h* (dummy) is a dummy variable equal to one if SO2 hourly emissions exceed the AQFD limit value. The variable *RegAQ SO2h* (number) indicates the number of exceedances of SO2 hourly limit value. ln *Ener* is sector energy intensity expressed as the logarithm of energy consumption over value added. Robust standard errors clustered by bilateral country-pair in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

in Figure 4. An increase in the minimum monthly average of the ventilation coefficient decreases exceedances of SO2 limit values whenever we consider the exceedance dummy (Column 1) or the number of exceedances (Column 2). Thus, favourable weather conditions (a higher ventilation coefficient) imply a higher ability in a given country to disperse air pollutant concentration.

At the top of Table 6, we present the second-stage results. Control variables are significant and have the expected sign. Our coefficient of interest is positive and significant at the 5% level (Column 1), indicating that EU countries implementing more stringent regulations import relatively more in pollution-intensive sectors. In Column 2, we redo the estimation using the number of exceedances instead of the dummy variable. We find that the effect of the environmental regulation is basically unchanged and remains significant at the 5% level.

Note that IV estimates are generally larger than OLS estimates. This downward bias in OLS estimation is consistent with previous evidence (Broner et al., 2012). It seems to indicate that the endogeneity problem relates either to measurement errors or to two potential sources of reverse causality. First, industry lobbying may prevent countries with larger industrial polluting sectors to implement environmental measures constraining these sectors. Second, countries importing a great deal of pollution-intensive goods may generate less pollution, thus leading to a decrease in the number of exceedances. Taking into account the endogeneity issue strengthens the evidence that EU air pollution regulation increases imports of polluting goods from the ECA region.

6 Conclusion

Air pollution is a major issue for emerging and developing countries in Europe and Central Asia, whereas their main trading partner - the EU - has undertaken increasing efforts to protect the environment by adopting stricter environmental regulations. This paper investigates whether tighter EU air quality regulation fosters ECA countries' specialization in polluting activity.

We use an original and unexplored variable that evaluates regulation stringency and limits simultaneity issues, based on the EU AQFD. Furthermore, we isolate the specific effect of regulation from any omitted factor influence by examining the underlying mechanism: the regulation's impact should be larger in pollution-intensive sectors. Focusing on this conditional effect of environmental policy allows us to include an extensive set of fixed effects. We also address endogeneity in the relation between environmental regulation and trade by adopting a reliable instrumentation strategy. As an exogenous instrument for environmental stringency, we rely on the climate variability's impact on short-term air pollution concentration.

We find that tighter EU air quality regulation leads to a significant increase in ECA exports in pollution-intensive industries. We also confim previous evidence that an empirical strategy addressing possible bias allows us to disentangle pollution haven effects from other influences (e.g. Levinson and Taylor, 2008).

Our findings highlight the possible adverse effects of air pollution regulation in Europe. To the best of our knowledge, the effectiveness of European air quality policies and their global impact have been poorly investigated. Our results suggest that these policies are effective because they compel EU countries to implement more stringent environmental programs. However, they also lead to an increase in imports of pollution-intensive goods from developing and emerging countries with weaker air pollution regulation. Therefore, if the objective of such legislation is to improve air quality globally, it should be implemented in all countries.

This paper suggests a number of directions for future research. Our strategy can be extended to the case of foreign direct investment. A large body of literature has examined the potential effect of environmental regulation on outsourcing polluting activity. However, the evidence so far has shown only limited effects. The AQFD provides an interesting framework to study the effect of environmental stringency on EU outward - and inward - investments. In addition, the evidence of a pollution haven mechanism in ECA countries also calls into question the economic consequences of deeper energy- and pollution-intensive specialization in this region. The high industrial 'endowments' in energy-intensive sectors in Eastern European countries is a direct legacy of the distorsions implied by the Soviet-type economic system, raising concerns about the growth consequences of maintaining a high reliance on energy- and pollution-intensive industries.

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Appendix A: Data

Table A.1: Pollutant limit values from the first Daughter Directive (1999/30/EC)

Pollutant	Concentration	Averaging period	Limit value enters into force	Allowed exceedances each year
Sulphur dioxide (SO2)	350 μg/m3	1 hour	1.1.2005	24
	125 μg/m3	24 hours	1.1.2005	3
Nitrogen dioxide (NO2)	200 μg/m3	1 hour	1.1.2010	18
	40 μg/m3	1 year	1.1.2010	None
Oxides of nitrogen (NOx)	30 μg/m3	1 year	19.07.2001	None
PM10	50 μg/m3	24 hours	1.1.2005	35
	40 μg/m3	1 year	1.1.2005	None
Lead (Pb)	0.5 μg/m3	1 year	1.1.2005 (or 1.1.2010 in specific cases)	n/a

Notes: Lead limit value enters into force in 1.1.2010 in the immediate vicinity of some specific industrial sources. The second Daughter Directive (2000/69/EC) introduces limit values for Benzene and Carbon Monoxid. The third Daughter Directive (2002/3/EC) establishes target values for Ozone. The fourth Daughter Directive (2004/107/EC) completes the list of pollutants and imposes limit values for arsenic, cadmium, nickel and polycyclic aromatic hydrocarbons.

Table A.2: Data description and sources

Variables	Description and sources
M_{ijst}	Bilateral imports of EU 27 countries from 11 Eastern European countries at the sector level. Data come from the UN Comtrade database.
$\mathrm{Distance}_{ij}$, $\mathrm{Contiguity}_{ij}$	Bilateral distance and contiguity dummy variables come from the CEPII database.
$Ener_{js}$	Sector (2 digits) energy intensity. Defined as energy consumption (in kg of oil equivalent) over output (in constant 2005 dollars). Heating energy is excluded. Data on energy consumption is provided by the International Energy Agency and sector value added data come from UN Industrial Development Organization (UNIDO).
Fossil $Ener_{js}$	Sector (2 digits) fossil fuel energy intensity. Defined as non-electric energy consumption (in kg of oil equivalent) over output (in constant 2005 dollars). This variable encompasses oil, gas and coal sources of energy. Data on energy consumption is provided by the International Energy Agency and sector value added data come from UN Industrial Development Organization (UNIDO).
$Ener_s^{US}$	Normalized measure of U.S. sector (4 digits) energy intensity. Defined as the ranking of sector fixed effect coefficients in the estimation of sector energy intensity as in equation (A.1), over the period 1990-2009. This variable is computed using data from the Manufacturing Industry Database provided by the National Bureau of Economic Research (NBER) and the U.S. Census Bureau's Center for Economic Studies (CES). See above for more details.
$RegAQ\ SO2h_{it}$	Environmental regulation proxy. This variable is a dummy that takes the value 1 if SO2 emissions exceed the SO2 hourly limit value more than twenty four times a year (which is the number of exceedances allowed each year). As an alternative proxy, we use a variable that counts for every country and year the number of exceedances of SO2 hourly limit value, whenever this number exceeds twenty four. In other cases, this variable equals to zero. Data on the number of exceedances come from the AirBase database (European Environment Agency, EEA).
SOx $\mathrm{Emissions}_{it}$	Annual national total emissions of sulphur oxides SOx (SO2 and SO3) reported by EU countries to the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP Convention). Source: European Environment Agency (EEA).
Minimum Monthly Ventilation $\mathrm{Coefficient}_{it}$	This variable is the minimum ventilation coefficient for each EU country and year. Ventilation coefficient is computed by multiplying wind and mixing height of the geographic grid where are located air quality monitoring stations. Wind and mixing height information is provided by the ERA-Interim data from the European Centre for Medium-Term Weather Forecasting (ECMWF). Geographic coordinates of monitoring stations of EU countries are obtained from the AirBase database (EEA).

A.1 Derivation of energy intensity at the sector level ($Ener_s^{US}$)

To compute a variable for energy intensity varying only at the sector level, we use U.S. manufacturing data providing industry-level energy expenses at the 4-digit level. These data are not endogenously affected by differences of environmental stringency implied by the AQFD and provide consistent estimates of the extent a given sector is affected by air pollution regulation. Finally, US-based data bring two other benefits: large sector coverage and relatively weak market distortions. The basic approach to define structural energy intensity would be to divide energy expenses over gross output and compute the mean over a given period (or use a particular year). This methodology nevertheless presents two main caveats. First, averages may be biased by yearly shocks. Second, the amount of self-produced intermediate inputs affects the consumption of energy. One way to determine an industry energy-intensity attribute independent from U.S. market specificities is to regress energy expenditures on sector value added. A similar strategy is adopted by Boyd and Curtis (2014). Thus, the industry structural energy intensity specification is as follows:

$$lnEE_{st} = \beta_0 + \gamma_1 \ln VA_{st} + \delta_s + \theta_t + \mu_{st} \tag{A.1}$$

where s denotes the 4-digit manufacturing sector and t denotes the year; EE are the energy expenses (in constant 1987 dollars); VA is value added measured as gross output minus non-energy material costs. The information about the sector's structural energy intensity is provided by the coefficient of the sector fixed effect δ_s. We define the reference sector as that depicting the highest coefficient, i.e., the sector engaged in primary production of aluminium (SIC code 3334). Thus, compared to the "primary production of aluminium" industry, all other sectors should display negative coefficients. The estimation also includes year fixed effects θ_t. Finally, μ_{st} is the error term.

To ease interpretation, we normalize sector dummy coefficients to generate a variable varying between 0 and 1. The normalized measure of a sector's energy intensity is defined by:

$$Ener_s^{US} = 1 - \frac{\delta_s}{min(\delta_s)} \tag{A.2}$$

Thus, an increase in the variable $Ener_s^{US}$ indicates higher structural energy intensity, with the most energy-intensive industry displaying a value equal to 1.

To compute the variable $Ener_s^{US}$ we use the NBER-CES Manufacturing Industry Database. This dataset covers 459 4-digit-level U.S. industries from 1958 to 2009. We use uniquely data from the 1990-2009 period.

Table A.3: Top 5 and flop 5 sectors according to their energy intensity

	SIC code	SIC name	Coefficient on sector dummy (δ_s)	$Ener_s^{US}$
Less energy intensive	2131	Chewing and smoking tobacco and snuff	-5.9382	0
	2721	Periodicals publishing and printing	-5.6206	0.0535
	2731	Books publishing and printing	-5.6008	0.0568
	2121	Cigars	-5.5884	0.0589
	3171	Women's handbags and purses	-5.5707	0.0619
Most energy intensive	2813	Industrial gases	-1.2167	0.7951
	3241	Cement, hydraulic	-1.1849	0.8005
	3312	Steel works, blast furnaces and rolling mills	-1.0736	0.8192
	2812	Alkalies and chlorine	-0.8252	0.8610
	3334	Primary production of aluminium	0	1

Table A.3 describes the coefficient estimates and the normalized measure of sector energy intensity (ENER) of the 5 most and least energy-intensive sectors. Except for both extremes, all sector dummies depict negative and statistically significant coefficients at the 1 percent level. Among the top 5, four sectors belong to primary metal industries (3334 and 3312) and chemicals (2812 and 2813). The least energy-intensive sectors include mainly printing and publishing products and tobacco products. Unsurprisingly, tobacco products are also among the least capital-intensive sectors (Rajan and Zingales, 1998).

Appendix B: Additional robustness checks

Table B.1: PPML estimations

	OLS (1)	PPML Imports>0 (2)	PPML All flows (3)
RegAQ SO2h$_{it}$ (dummy)$\times \ln Ener_{js}$	0.173**	0.125**	0.126**
	(0.0672)	(0.0574)	(0.0579)
Distance (ln)	-2.269***	-1.869***	-1.890***
	(0.256)	(0.283)	(0.280)
Contiguity	0.751***	0.0125	0.0213
	(0.247)	(0.280)	(0.282)
Constant	24.92***	9.368***	9.388***
	(1.889)	(1.823)	(1.811)
Importer-year fixed effects$_{it}$	Yes	Yes	Yes
Exporter-year fixed effects$_{jt}$	Yes	Yes	Yes
Importer-sector fixed effects$_{is}$	Yes	Yes	Yes
Exporter-sector fixed effects$_{js}$	Yes	Yes	Yes
Observations	20,223	20,223	29,179

Notes: The dependent variable is the logarithm (Column 1) or the value (Columns 2 and 3) of bilateral imports. The variable *RegAQ SO2h* (dummy) is a dummy variable equal to one if SO2 hourly emissions exceed the AQFD limit value. $\ln Ener$ is sector energy intensity expressed as the logarithm of energy consumption over value added. Robust standard errors clustered by bilateral country-pair in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$