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Abatement expenditures, technology choice, and environmental performance: Evidence from firm responses to import competition in Mexico

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ABSTRACT

Abatement expenditures are not the only available tool for firms to decrease emissions. Technology choice can also indirectly affect environmental performance. We assess the impact of import competition on plants' environmental outcomes. In particular, exploiting a unique combination of Mexican plant-level and satellite imagery data, we measure the effect of tariff changes due to free-trade agreements on three main outcomes: plants' fuel use, plants' abatement expenditures, and measures of air pollution around plants' location. Our findings show that import competition induced plants in Mexico to increase energy efficiency, reduce emissions, and in turn *reduce* direct investment in environmental protection. Our findings suggest that the general technology upgrading effect of any policy could be an important determinant of environmental performance in developing countries and that this effect may not be captured in abatement data.

1. Introduction

Reductions in trade barriers between developed and developing nations can affect the environment in a variety of ways: through changes in the location of production (Grossman and Krueger (1992), Copeland and Taylor (1994), and Antweiler et al. (2001))[1] and consumption across countries (Davis and Kahn (2010)), or through resource reallocation from low-productivity to high-productivity plants within and across nations (Holladay (2016) and Yokoo (2009)).

For the U.S., recent literature has shown that improvements in environmental outcomes can also be driven by a change in technology (Levinson (2009)), and that this change can occur within plants (Shapiro and Walker (2017)). Specifically in the U.S. context, changes in regulatory effort are the main drivers of the change in technology choice. Nonetheless, the channels through which trade can affect environmental outcomes, and the consequences of those changes in developing countries may differ substantially from those in developed nations.

Pollution concentrations in developing countries are remarkably higher, and lower environmental quality can be both attributed to inferior technology and low regulatory capacity (Greenstone and Jack (2015)). Bloom et al. (2013) shows that gains from better management practice is substantial for Indian textile firms. If firms in developing countries are then further away from the technological frontier or best management practice, the potential impact of trade on technological choice can play a larger role in these contexts than in developed nations. A broad understanding of the impacts of trade on environmental outcomes seems also particularly relevant in developing countries, as high pollution levels impose larger health and productivity costs.[2]

The trade literature has accumulated evidence in the context of developing countries that the impact of trade on technology choice is substantial.[3] In particular, in the same Mexican context, Teshima (2010) finds that a decline in Mexican trade barriers induced Mexican firms to upgrade their technology. In light of these findings, we explore whether in the same context, tariff reductions had an indirect effect on

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[1] Copeland and Taylor (2003) summarize nicely the literature in this line of research.

[2] For example, see Arceo et al. (2016) and Hanna and Oliva (2015).

[3] See, for example, Verhoogen (2008) and Bustos (2011). Tanaka (2017) analyzes the impact of trade on management practice in Myanmar.

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environmental outcomes precisely through their impact on technology choice.[4]

Being aware of the different challenges for the control of and the consequences of pollution concentrations in developing countries, economists and policy makers have implemented policies aimed at improving regulatory capacity (Duflo et al. (2013) and Foster and Gutierrez (2016)), and fostering the adoption of cleaner technologies by firms (Ryan (2015)).[5]

As for the evaluation of these policies, measuring the impact of a decrease in trade barriers on environmental performance is a very difficult task, as it requires concrete and reliable measures of environmental performance at the firm level, which are relatively hard to obtain, particularly in developing countries. While looking at intermediate outcomes such as energy efficiency (Ryan (2015)) or abatement expenditures (Wang (2002)) may be informative, the final mapping of these measures into total emissions may not be trivial (Conrad and Morrison (1989)). Furthermore, the environmental impact of any policy that affects technology choice can be particularly hard to gauge when only intermediate measures of environmental performance are available. For instance, if the adoption of new technologies decreases emissions, it may also decrease abatement expenditures (particularly if these are devoted to end-of-pipe abatement strategies). This point has been long recognized, at least implicitly, but finding evidence is hard because researchers would need data on all of the abatement effort, technology and environmental outcomes and an exogenous shock to firm behavior to disentangle the causality.

In this paper, we show that in the Mexican context, abatement expenditures and technological change can respond differently to a change in trade tariffs, exploiting a unique combination of Mexican plant-level and satellite imagery data that together allow us to construct three main outcomes: plants' fuel use, plants' abatement expenditures measured as investment in efficient energy and environmental protection, and measures of air pollution around plants' location. As an exogenous factor to firms, we analyze import competition induced by free trade agreements.[6] Constructing firm-specific and time-varying measures of output tariffs faced by Mexican firms during the 2000–2003 period, we explore whether tariff changes affect energy efficiency, abatement expenditures and pollution concentrations around plants' locations, controlling for industry-specific and state-specific time variation in the outcomes of interest.[7] We find that import competition is related to an increase in plants' energy efficiency, but a decrease in abatement expenditures.[8] The overall effect of import competition on environmental quality is then impossible to infer from these two counteracting forces, particularly in a setting in which reliable measures of emissions at the firm level are unavailable. We provide further evidence on the impact of import competition on pollution concentrations by exploiting particulate matter concentration measures obtained from satellite-imagery, finding small but positive reductions in particulate matter concentrations around firms' location as a result of import competition.

Our results show that the impact of trade barriers on technology choice and, as a result, environmental outcomes are an important mechanisms for a broader understanding of the impact of trade on the environment in developing countries' settings. Moreover, they suggest than even when detailed data at the plant level are available, caution should be taken when trying to measure the effects of any policy on environmental performance. In our setting, one would have been tempted to conclude that import competition affects the environment negatively if only abatement expenditures had been available. Since trade has effects not only on the incentives to pollute but also on the adoption of different technologies (which may already be more efficient and less polluting), abatement expenditures may decrease even as emissions decrease. It is then necessary to obtain data both on plants' abatement expenditures and on environmental performance in general, in order to better understand the relationship between output price (driven in this case by trade openness), technology adoption, and the aggregate effect of both on pollution emissions. This message generally applies to any evaluation of the determinants of environmental performance.

Our paper is related to several strands of literature. As in other topics in international trade, trade economists have been increasingly analyzing firm/plant level data to study the relationship between trade and the environment. Holladay (2016) theorizes that exporters pollute less per unit of output than non-exporters in the same industry, and finds supporting empirical evidence for US plants. Forslid et al. (2015) advance this line of research further finding both theoretically and empirically that this is because exporters invest more in abatement. In a developing country context, Barrows and Ollivier (2014) further analyze the impact of export market access on firm-level product choice and its consequences on firm-level substance use by Indian firms.[9] Rodrigue and Soumonni (2014) analyze the relationship between exports and environmental innovation, using direct investments in environmental protection as an outcome. Most of the papers analyze exports. An exception is Cherniwchan (2017), who analyzes the impact of NAFTA on the emission of U.S. plants. Apart from focusing on the impact of trade on environmental outcomes for the Mexican context, our paper differs from Cherniwchan (2017) by looking at the interaction between self-reported information on environmental performance and independently collected measured of pollution concentrations form satellite imagery.[10] In addition, an important message of our paper is that improvement in energy efficiency and thus environmental quality due to trade may not be found in abatement data.

Apart from exploring a different channel through which trade can affect developing countries' firms' environmental performance, while focusing on a very specific policy change apparently unrelated to environmental regulations, our results are informative to the literature that measures the effect of different policies on environmental outcomes (Duflo et al. (2013) and Foster and Gutierrez (2016)). Our paper also speaks to the literature trying to test for a link between environmental regulation and technological choice (Porter (1996), Jaffe et al. (2002) and Acemoglu et al. (2012)) and between input prices and innovation (Popp (2002)). An important message from this paper

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[4] Throughout the text, we use the term "technology choice" rather broadly. As we will explain in better detail below, the data at hand makes it impossible to identify the precise technological changes that drive the changes in environmental performance in this context. The robustness section presents evidence suggesting that the main driver of the increases in energy efficiency is very likely a change in cost-cutting practices and improvements in technical efficiency.

[5] Policies that try to encourage households to adopt cleaner technologies have also been implemented. See for example Davis et al. (2014).

[6] We show in the data section that substantial fractions of the tariff reduction during this period is driven by phaseout of tariffs due to NAFTA. This is attractive for our purpose as Kowalczyk and Davis (1998) argue that Mexican tariff reductions due to NAFTA were driven by U.S. interests, and not those of Mexican firms. We present further econometric evidence on this point in Section 5.

[7] Our empirical strategy is similar to that in Teshima (2010), which finds that import competition has an effect on firms' technology choice, but we provide independent and more checks on the assumption of exogeneity of tariffs in our context and sample.

[8] We are not the first to interpret a reduction in output tariffs as an increase in competition. See, for example, Holmes and Schmitz (2010) and De Loecker and Goldberg (2014).

[9] Lipscomb (2008) also extends Melitz's heterogeneous-firm model to analyze how environmental regulation affects the production decisions of multi-product plants, and how the reallocation of resources resulting from these decisions affects industry-level environmental outcomes in India.

[10] The classic papers concerning the effect of trade on the environment are Grossman and Krueger (1992), Copeland and Taylor (1994, 1995). Antweiler et al. (2001) disentangle the effects of trade into scale, composition and technology effects. Our paper highlights a particular channel through which trade could affect the environment through its effect on technology, although there are other channels. Analyzing them and decomposing the whole effects through which trade could affect the environment is beyond the scope of this paper.

is that the fact that firms might lower their emissions of via cost-saving process improvements, either through technology upgrading or management practice, but without investment in abatement, should be considered when designing environmental policy for developing countries.

Finally, our paper is also related to studies using satellite image data. The use of data obtained from satellite imagery has become a widespread practice in empirical papers in economics (Donaldson and Storeygard, 2016). In particular, the use of Aerosol Optical Depth (AOD) as a measure of particulate matter concentrations is not unique to this paper.[11] The usefulness of AOD measures of particulate matter concentrations relies on their availability in contexts where no ground measures of pollution concentrations exist, and on the independent nature of the data collection process, which does not respond to political pressures. All Bombardini and Li (2016), Gutierrez (2015) and Chen et al. (2013) document a very close relationship between ground measures and estimates of pollution concentrations and AOD in contexts in which both are available.

To our knowledge, apart from this paper, only Bombardini and Li (2016) measure the impact of trade shocks, export market access in their case, on environmental quality using AOD as dependent variable. Apart from the difference in the particular channel of trade in which their and our study focus respectively, the main innovation in our study is then to compare the results using remote sensing images with those that can be indirectly inferred from survey measures of environmental performance which, may lead, as we show, to misleading conclusions. In particular, we use them to explore how the interaction between changes in direct investment in abatement efforts and in fuel use from the part of firms sum up to the total change in air quality as a result of trade shocks.

This paper is organized as follows. The next section describes the new combination of datasets, and presents descriptive statistics of plant-level variables as well as the air pollution measures. Section 3 describes our econometric strategy. Section 4 presents the key results of the effects of competition on plants' energy efficiency, environmental investment, and the pollution level at the plants' locations. Section 5 presents a series of robustness checks. The final section concludes.

2. Data

2.1. Plant-level data

We combine three types of plant-level data for the analysis. The first is a specialized survey on innovative activities from which we draw abatement expenditures, measured as investment in environmental technology. The second is a standard plant-level survey from which we draw information on energy efficiency, measured as expenditure on fuel and electricity divided by total sales. The third is a registry of plants that includes information on the trade-classification category of plants' outputs and inputs from which we construct measures of plant-level tariff changes.

2.1.1. ESIDET

The source for the information on the environmental and energy investment is the *Encuesta Sobre Investigación y Desarrollo de Tecnología* (ESIDET) [Survey on Research and Development of Technology]. This is a confidential survey carried out by the Instituto Nacional de Estadística, Geografía (INEGI) [National Institute of Statistics and Geography] of Mexico for the Consejo Nacional de Ciencia y Tecnología (CONACYT) [National Council of Science and Technology].

The survey contains information on several aspects of innovative activities of manufacturing plants: expenditures, human resources and collaboration between firms and research institutions. It includes information on expenditures for each type of R&D: product R&D and process R&D. We use the 2002 and 2004 surveys. Each survey elicits information for the previous two years. This allows us to construct an unbalanced panel from 2000 to 2003. In addition to the standard technology-related variables, the survey asks how much plants spend on socio-economic activities. Specifically, the survey asks how much plants spend on (1) care and control of the environment (cuidado y control del medio ambiente), which includes prevention, detection and improvement of contamination of land, water, and air,[12] (2) rational production and use of energy (Producción y uso racional de la energía),[13] and (3) health except pollution reduction (salud (excluyendo contaminación)). We use (1) and (2) as abatement expenditures for the main analysis and (3) in the robustness check section. We call (1) environmental investment, (2) energy investment and (3) health investment.[14]

There are ESIDET surveys for the various sectors. The survey for the manufacturing sector addresses plants with more than 50 employees. The survey uses the Economic Census of 1999 to draw a sample. Among the plants in the Economic Census of 1999, the plants with more than 500 employees are included in the sample with certainty.[15] Plants with at most 500 employees are sampled with probability depending on whether they have employees (a) between 50 and 100, (b) 101 and 250 and (c) 251 and 500.

2.1.2. EIA

In order to obtain energy-related expenditures and sales, and thus energy efficiency, we draw the *Encuesta Industrial Anual* (EIA) [Annual Industrial Survey]. The EIA is a longitudinal plant level dataset in 205 of the 305 6-digit industries in manufacturing. The EIA is also compiled by INEGI. EIA sampling design selects largest producers from Economic Census and continues adding to sample until the target share, 85 percent, of the covered domestic sales at each industry is reached.[16]

2.1.3. SIEM

For information on the output and input categories of the firms to calculate output and input tariffs at the plant level, we use the *Sistema de Información Empresarial Mexicano* (SIEM) [Mexican Company Information System] compiled by Mexico's Secretaría de Economía [Ministry of Economy]. It is a directory of firms in Mexico to facilitate business contacts between firms in Mexico and foreign firms. SIEM lists firms' inputs and outputs at the 6-digit or 8-digit trade-classification level regardless of whether the firms export or import. It does not have information on the volumes of each output or input, or on whether the plants export or import. The SIEM starts in 1997, but detailed information about firms' inputs and outputs are available only from 2001. Firms are legally obliged to report; therefore in principle the SIEM can be regarded as a census of firms in the formal economy. The SIEM has

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[11] See for instance Gutierrez (2015) and Foster et al. (2009) for papers using these data for the Mexican context, and Jayachandran (2009), Chen et al. (2013) and Bombardini and Li (2016) for studies in other contexts than the Mexican.

[12] An example of this type of investment is investment for development and installation for measuring, preventing and controlling pollutants.

[13] An example of this type of investment is investment for generating and distributing electricity within plants. Importantly for our purpose, expenses on energy efficient equipment are not included.

[14] Both environmental and energy investment may be noisy for our purposes. Environmental investment may contain effort towards reducing water or land pollution, while we focus on air pollution. Energy investment may include investment on production of energy. We find that the results are similar though sometimes less precise when we analyze environment investment and energy investment separately. Importantly, these investment refers only to technology-related investment, thus excludes advertisement expenditures, for example.

[15] Plants for Tobacco, Ship-building, Airplane, and Electronic components are included with certainty regardless of the size.

[16] Further details on EIA can be found in Appendix II in Verhoogen (2008).

been linked by INEGI personnel to the EIA and ESIDET using information on firm name, state, municipality, street address, and industry.

2.2. Descriptive statistics of plant-level variables

Appendix Table B.1 presents summary statistics of environmental and energy investment for the ESIDET-EIA-SIEM panel. Consistent with the trade literature on exporting firms, exporters are larger in terms of employment. Exporters not only spend more on fuel and electricity but also have a higher share of these expenditures on total sales, though this may be reflecting the industry composition of exporters and non-exporters. Exporters are more likely to be engaging in environmental and energy investment and have higher expenditure. However, only 6% of these exporters report a positive amount of environmental investment. This ratio is 4% for all the plants and 2% for non-exporters.

2.3. Satellite imagery data

In order to assess the overall impact of the changes in tariffs on plants' environmental performance, we constructed a zip-code level dataset, which assigns, along with measures of weighted tariff changes in each zip-code, measures of pollution concentrations in the atmosphere around them. For this, we obtained daily measures of Aerosol Optical Depth (AOD) at a 5 km spatial resolution for cloud-free images for the entire land area of Mexico over the 2000–2003 time period. A higher value of AOD means less transparency (lower air quality). The data were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS onboard the Terra Satellite), of NASA's Goddard Space Flight Center Earth Sciences Distributed Active Archive Center (DAAC). Aerosols are liquid and solid particles suspended in the air, and AOD can be described as the extinction of beam power caused by the presence of these particles in the atmosphere. AOD measures obtained form satellite imagery are particularly useful in contexts where no ground measures of pollution concentrations exist, and are likely to be more reliable than alternative sources due to the independent nature of the data collection process. For the Mexican context, these AOD measures have already made it possible to evaluate pollution abatement policies (Foster and Gutierrez (2016)), and their potential relationship with health outcomes (Gutierrez (2015, 2010) and Foster et al. (2009)).[17]

The strong relationship between AOD and other measures of particulate matter concentrations in the atmosphere is well documented in the existing literature. For example, Bombardini and Li (2016), Gutierrez (2015) and Chen et al. (2013) document a very close relationship between ground measures and estimates of pollution concentrations and AOD in contexts in which both are available.[18] Kumar et al. (2007) show that linear regression estimates suggest that a 10 percent change in AOD explains a 0.52 percent change in their ground measure of particulate matter (PM2.5,) with an R-squared of 0.71. However, while AOD is a good predictor of general levels of suspended particles in the atmosphere, it is worth mentioning that it does not allow to make any distinction between pollutants, and that comparisons across regions with different climate and geographic conditions are hard to make. Our analysis will then focus on changes in AOD levels within zip codes.

As the information at the plant level is available yearly in our analysis, we constructed a measure of the average yearly AOD level for each zip code in our data set.[19] Using GIS, the observed measures of AOD from the satellite images were overlapped with each zip-code's exact geographic locations. The estimated AOD daily value for each zip-code was averaged for each month in the sample. The yearly average is the mean of all monthly averages.

2.4. Descriptive statistics of the pollution measure

Appendix Fig. B.1 shows a map with the calculated AOD level for the year 2000 in all Mexican zip codes for which we have precise geographic coordinates and for which AOD measures are available. The lighter dots represent zip codes with lower AOD levels. Although, as stated, differences in AOD levels across regions can be due to geographic and climatic conditions unrelated to concentrations of particulate matter, AOD measures do appear higher around metropolitan areas and along the Gulf Coast (possibly due to the importance of the oil industry in this region). Appendix Fig. B.2, in contrast, maps the changes in our AOD measure within zip codes between 2000 and 2003. Darker dots represent the zip codes that experienced higher increases in AOD during this period. Clear geographic patterns on the increase or reduction of our AOD measures during the period are not evident.

Appendix Table B.2 shows statistics for both AOD levels in 2000 and changes in AOD between 2000 and 2003 for all 378 zip codes matched with our firm-level dataset. The mean AOD level in our sample in the year 2000 was 0.39, ranging from 0.02 to 0.98 and with a standard deviation of 0.22. As our regression estimates difference out variations in AOD levels across zip codes with the zip code fixed effects, the relevant variation exploited in this paper corresponds to changes in this variable. Between 2000 and 2003, for all zip-codes in our sample, the change in AOD (on average close to zero) ranges from −0.32 to 0.38 with a standard deviation of 0.09 (more than 20% of the average AOD level in 2000). To put this variation in context, it is perhaps useful to mention that Foster et al. (2009), exploiting variation in AOD and infant mortality within municipalities, found that the elasticity of infant mortality with respect to AOD in Mexico is approximately 4.

2.5. Tariff data

We construct tariff data using (1) Mexican import statistics published in trade statistics yearbooks and (2) tariff information from the tariff law of Mexico and from the documents of the free trade agreements between Mexico and other countries. The first subsection describes the method to calculate plant-level tariffs. The second subsection describes the summary statistics for the tariff data.

2.5.1. Construction of plant-level tariff measures

Because of free trade agreements, tariffs for one product differ depending on the country of origin. We first aggregate the country-good specific tariffs to good-level tariffs by taking the weighted average with the initial volume of imports used as weights. $Imports_{gjct}$ is imports of good g in industry j from country c at time t. $Tariff_{gjct}$ is tariff of good g in industry j from country c at time t.

$$Tariff_{gjt} = \sum_{c} \alpha_c Tariff_{gjct} \tag{1}$$

where $\alpha_c = \frac{Imports_{gjc2000}}{\sum_c Imports_{gjc2000}}$.

Next, using this good-level tariff data $Tariff_{gjt}$, we take the simple average of the tariffs of each plant's outputs to construct the output tariffs at the plant level.[20]

$$Output\ Tariff_{igt} = \frac{\sum_{g \in G_i} Tariff_{gjt}}{N_i} \tag{2}$$

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[17] See Jayachandran (2009), Chen et al. (2013) and Bombardini and Li (2016) for studies in other contexts than the Mexican.

[18] See also Chu et al. (2003) and Gupta et al. (2006).

[19] We find qualitatively similar effects when we use 95 percentile of yearly AOD and when we calculate the average level of AOD of each month and use the highest value among monthly AOD for a given year.

[20] We have to use the simple average because SIEM data does not allow one to obtain the information on the volumes of each product by plant.

where G_i is the set of products that plant i produces, and N_i is the number of products of plant i produces, respectively.

Similarly, we take the simple average of the tariffs of each plant's inputs in the initial period to construct the input tariffs at the plant level. Note that we always use the outputs and inputs information from year 2001 to compute the output and input tariffs for each year.[21] Thus all the variation of the tariff of a good is coming from the changes in the tariff of the good but not from the changes in the volume of the imports of the good. This is to avoid bias due to the changes in output mix or in input mix in response to the tariff reduction.

When we calculate the weighted average tariffs for imports from all the countries as well as from four groups of sets of countries: NAFTA, EU, countries to which most favored nations (MFN) tariffs are applied, and other countries that are not in NAFTA or in EU and that have a free trade agreement with Mexico, we see that the tariff changes are largely coming from tariff changes scheduled, late NAFTA liberalization and the free trade agreement with EU. In terms of plant-level tariffs, average output tariffs decreased from 7.7% in 2000 to 4.1% in 2003. Appendix Table B.3 presents summary statistics for tariffs. It shows that the tariff changes are largely coming from tariff changes scheduled in free trade agreements, evidencing that changes are exogenous.

3. Specification

3.1. Plant-level analysis

The baseline econometric model is the following:

$$Y_{ijt} = \beta_1 Output\ Tariff_{it} + \lambda_i + \mu_{jt} + \epsilon_{ijt} \tag{3}$$

where i, j, and t index plants, industries, and years, respectively; Y_{ijt} denotes the dependent variable: (Inverse) energy efficiency measured as the share of expenditures on fuel or/and electricity over total sales, abatement expenditures measured as the sum of environmental investment and energy investment; $Output\ Tariff_{it}$ is output tariffs at the plant level constructed in the manner described in the tariff data section; λ_i is a plant fixed effect; μ_{jt} is an industry-year fixed effect; ϵ_{ijt} is an error term.[22]

The coefficient of interest in these regressions is β_1. β_1 corresponds to the changes in the dependent variables in response to a one percent point change in the output tariff, which captures (the inverse of) the effect of competition. The plant fixed effects capture all observed or unobserved time-invariant heterogeneity across plants. The industry-year fixed effects capture all observed or unobserved shocks at the industry level. Thus, the coefficient of interest is identified on the basis of within-plant changes in the three types of tariffs and within-plant changes in the dependent variables controlling for industry-level idiosyncratic shocks. The identification assumption of this econometric model is that no unobservable factors are correlated with the output tariffs after controlling for time-invariant plant-level heterogeneity and industry-level idiosyncratic shocks.

Note that a positive value of the coefficient means that output tariff reduction affects the dependent variable *negatively*. A priori, there is no clear theoretical prediction on whether the coefficients should be positive or negative. In some specifications, we also control for state-year fixed effects to control for any shocks at the region level.

3.2. Zip-code level analysis

As stated, in order to assess the aggregate effect that the changes in plant-level outcomes translate into changes in pollution emissions, we present a set of results relating the changes in tariffs to changes in environmental performance by directly looking at measures of pollution concentrations around plants' location. If a measure of environmental performance at the plant level were available, we would run the same specification as in the previous sub-section, using this measure as our outcome variable. However, AOD measures pollution concentrations in the atmosphere at the zip-code level, and more than one plant can be located in the same zip-code. We then assume that the pollution concentrations in each zip-code are a weighted average of the pollution emissions by each plant in that zip-code. We calculated a weighted average of the tariff variable in the main regression equation for each zip-code, using the total number of employees reported by each plant divided by the total number of employees in each zip code (the sum of the employees of all plants in the SIEM database in each zip code) as the weight for each of the plant-level observations, and run regressions, with each of these variables as regressors, at the zip-code level. Specifically, we run the following regression:

$$AOD_{zjt} = \beta_1 Output\ Tariff_{zt} + \lambda_z + \mu_{jt} + \gamma X_{mt} + \epsilon_{zjt} \tag{4}$$

where z denotes zip-code. λ_z captures the idiosyncratic effect of each zip-code. μ_{jt} is a dummy variable indicating whether the zipcode has any plants in industry j. γX_{mt} include municipality-level weather-related variables, more specifically temperature and dew, and their polynomials, taken from one of the authors' earlier work (Gutierrez (2015)).

4. Results

4.1. Results: plant-level measures

4.1.1. Results: energy use

Table 1 presents the regression results for different measures of energy use on the output tariff. Columns (1) and (2) use the sum of electricity and fuel expenditures over total sales as the dependent variable. Column (1) shows a positive and statistically significant coefficient for our measure of output tariffs, suggesting that an increase in competition *increases* energy efficiency in general. A one percentage point decrease in the output tariff implies that energy-related expenditures over sales fall by about 0.05 percentage points.[23] Column (2) shows that the result is robust to the inclusion of state-year fixed effects, suggesting that the results are not driven by changes in geographic conditions or state-level policies.

The next four columns show the results of the same specification, disaggregating the dependent variable into electricity over sales and fuel over sales. Column (3) of Table 1 shows that there is a significant and positive effect of output tariffs on electricity use over sales, suggesting that the increase in competition driven by the change in tariffs *increases* electricity efficiency. A one percentage point decrease in the output tariff implies that electricity expenditures over sales fall by about 0.02 percentage points.[24] This result is again robust to the inclusion of state-year fixed effects (Column (4)). Using fuel efficiency as the dependent variable, Columns (5) and (6) show that the coefficients of the output tariffs are similar in sign and quantitatively larger than those in the previous two columns. However, these coefficients are not significantly different from zero. Given this, it is difficult to conclude which of the two types of expenditure is most affected by the change in output tariffs.

Overall, we find in this analysis that the increase in import competition induced by output tariff reductions leads to an increase in the

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[21] This is not ideal as the plant-level data set starts in 2000. However, as product-level information is available at the SIEM only since 2001. The output and input composition does not change much at least between 2001 and 2002.

[22] In the robustness check section, we show that our results are robust to inclusion of other tariffs: input tariffs, which are Mexican tariffs imposed on plants' imported intermediate inputs, and US tariffs, which are US tariffs imposed on plants exports of outputs to US. Furthermore, we present results with robust standard errors. Results clustering standard errors at the industry level do not change the significance level of our coefficients of interest. The results are available upon request.

[23] The mean of energy-related expenditures over total sales is 2 percent.

[24] The mean of electricity expenditure over total sales is 1 percent.

Table 1
Regressions of the intensity of electricity and fuel over sales on output tariffs, ESIDET-EIA-SIEM panel 2000–2003[a].

Dependent Variable	(1) Sum	(2) Sum	(3) Electricity	(4) Electricity	(5) Fuel	(6) Fuel
Output Tariff	0.0481** (0.0235)	0.0551** (0.0274)	0.0262* (0.0149)	0.0223* (0.0133)	0.0262 (0.0344)	0.0258 (0.0315)
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes
State-year effects	No	Yes	No	Yes	No	Yes
Observations	1776	1776	1776	1776	1776	1776
R^2	0.17	0.22	0.18	0.22	0.19	0.23

[a] Notes: The table reports coefficients on the output tariffs from plant-level regressions of the intensity of expenditures on electricity and fuel over total sales on the output tariffs, plant fixed effects, industry-year fixed effects and in some cases state-year fixed effects. Plant-level output tariff for a plant is the simple average of the product-level tariffs of the products that the plants produce. Robust standard errors in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 2
Regressions of the environmental and energy investment on output tariffs, ESIDET-EIA-SIEM panel 2000–2003[a].

Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Sum of Environmental and Energy Investment					
	Intensity		Dummy		Log	
Output Tariff	0.0023* (0.0014)	0.0026* (0.0014)	0.0072** (0.0028)	0.0074** (0.0029)	0.059*** (0.021)	0.066*** (0.021)
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Region-year effects	No	Yes	No	Yes	No	Yes
Observations	1776	1776	1776	1776	1776	1776
R^2	0.23	0.27	0.24	0.27	0.22	0.27

[a] Notes: The table reports coefficients on the output tariffs from plant-level regressions of the intensity, dummy and the log of the sum of environmental and energy investment on the output tariffs, plant fixed effects and industry-year fixed effects. Plant-level output tariff for a plant is the simple average of the product-level tariffs of the products that the plants produce. Robust standard errors in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

energy efficiency of affected plants. Our interpretation is that this is due to the improvement in plants' general technology, which previous empirical studies have shown to be a result of the same tariff changes. Specifically, Teshima (2010) finds that, for the same plants and over the same time period, increased competition (measured by the same changes in output tariffs) increases total R&D and process R&D. These increases might have been accompanied by the adoption of new technologies which brought on savings in electricity and/or fuel expenditures. We return to this point in Section 5.2.

4.1.2. Results: environmental and energy investment

Next, we report the results of regressions that use measures of environmental and energy investment as dependent variables. We use three types of investment measures: investment intensity, measured as investment over total sales, the log of investment, and an investment dummy.

Table 2 shows the results. Columns (1) and (2) suggest that a one percentage point decrease in output tariffs implies a decrease in environmental and energy investment over sales by about 0.002 percentage points. Columns (3) and (4) suggest that the same decrease in output tariffs leads to a 0.7 percentage points decrease in the likelihood of investing in energy and the environment. Columns (5) and (6) suggest that the same one percentage point decrease in output tariff leads to a 5–6 percent decrease in the amount spent on such types of investment. Columns (2), (4) and (6) show the results after also controlling for state-year effects, suggesting that none of these results are driven by state-specific economic fluctuations. Overall, the increase in import competition induced by output tariff reductions led to a decrease in the environmental and energy investment of the affected plants.

4.2. Zip code level results on the pollution measure

The results on energy efficiency and environmental investment seem to go in opposite directions. While tariff reductions (increased competition) imply higher energy efficiency, they are also related to lower environmental investment at the plant level. The overall effect of the tariff change on environmental performance is therefore uncertain.

In order to shed some light into the aggregate effect of changes in tariffs on environmental performance, Table 3 presents the results for our zip code-level regressions, with our measure of pollution concentrations (AOD) as the dependent variable. Columns (1) only includes zip-code and industry-year effects and zip-code level controls such as total sales from the plants in our sample. Column (5) present the results including zip-code, industry-year and state-year fixed effects. Because, in our setting, air quality should improve if the positive effect of technology adoption is higher than the potential negative effect driven by the decrease in investment in preventing emissions, Columns (2) and (6) include an interaction term between initial AOD levels and output tariffs. The extent to which the scope for technology adoption to reduce emissions is larger for initially more polluting technologies, we expect the coefficient associated with this interaction to be positive. To explore this directly, we perform two types of analysis. First, Columns (3) and (7) include an interaction term between the output tariffs and the initial average energy intensity of plants in the zip code, constructed as total-sales-weighted average of energy use intensity of the plants in the zip-code. Second, Columns (4) and (8) include an interaction term between the output tariffs and a dummy variable indicating whether a zip code has at least one firm in a relatively more polluting industry.[25]

As Column (1) shows, the coefficient of the output tariff implies that tariff reductions decrease pollution concentrations around plants' locations. An increase of 1% in tariffs is associated with an increase in AOD of 0.0017 points (around 0.4 percentage points). The effect of the

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[25] We use the World Bank's Industrial Pollution Projection System (IPPS), which includes emission intensities by four-digit SIC code. We manually matched SIC code to the Mexican industry classification. We used the first principal component of emission intensity of CO, SO_2, and NO_2, and define relatively more polluting industries as industries whose value is higher than the median.

Table 3
Regressions of the AOD measure on output tariffs:2000-2003[a].

Dependent Variable	(1) AOD	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Output Tariff	0.002*	−0.009***	−0.006***	−0.007**	0.001	−0.008***	−0.007***	−0.007**
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)
Output Tariff		0.021***				0.016***		
*AOD2000		(0.005)				(0.005)		
Output Tariff			0.25***				0.19***	
*Energy Intensity 2000			(0.06)				(0.05)	
Output Tariff				0.027***				0.022***
*Dummy (Pollution Intensity more than Median 2000)				(0.006)				(0.005)
Zip-code fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Zip-code Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region-year effects	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1512	1512	1512	1512	1512	1512	1512	1512
R^2	0.96	0.96	0.97	0.97	0.96	0.97	0.97	0.97

[a] Notes: The table reports coefficients on the output tariffs and its interaction term with the initial level of AOD from zip-code level regressions of the AOD measure on the output tariffs, the interaction term, zip-code fixed effects, industry-year fixed effects and state-year effects. Zip-code-level output tariff is the weighted average of the plant-level tariffs of the products that the plants in the zip-code produce. Energy intensity 2000 is constructed by taking the zip-code level total-sales-weighted average of energy intensity (energy expenditure divided by total sales) of the plants in the zip-code. A variable, Pollution Intensity more than Median 2000, is a dummy variable indicating whether a zip-code has at least one firm in a relatively more polluting industry. Robust standard errors in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

output tariff is not robust to the inclusion of state-year effects; its coefficient becomes insignificant in Column (5). However, the effect of the output tariff for zipcodes with higher initial AOD, with higher energy intensity, or with plants in more polluting industries, is positive and statistically significant, with and without state-year effects (Columns (2), (3), (4), (6), (7) and (8)).

The results together show that the overall impact of tariff changes on pollution emissions is driven by changes in energy efficiency, and not by changes in environmental investment. This suggests that, through competition, trade liberalization can have distinct effects on plant-level environmental performance and that, even when direct abatement measures are available, empirical studies should be careful when interpreting results. Regulation is usually based on capping emissions, and trade has effects not only on the incentives to pollute but also on the adoption of different technologies. If this is the case, when adopting new, more efficient and less polluting technologies, abatement efforts (which are possibly made only to comply with environmental regulation, and not to improve overall efficiency) may decrease. We believe our results to suggest the need to obtain data both on plant's direct investment in pollution abatement and on environmental performance when trying to empirically test for the relationship between trade openness, technology adoption, and the aggregate effect of both on pollution emissions.

5. Robustness

5.1. Endogeneity concerns

Given the non-experimental nature of the variation in tariffs that we exploit in the empirical analysis, our identification strategy may fail to estimate the causal impact of tariff changes on the outcomes analyzed if there are omitted variables correlated with both our explanatory and dependent variables, or in the presence of reverse causality. In this section, we discuss the potential sources of bias, and present evidence suggesting that they are not likely an important concern for the interpretation of our findings. For this purpose, it is perhaps useful to recall that our preferred estimates control for differential time trends by industry (industry-year fixed effects), and differential trends by region (state-year fixed effects). The set of potentially omitted variables is then restricted to those that, as our measure of tariffs, vary differentially over time and across industries in the same region.

5.1.1. Prices

Obvious candidates to satisfy this last requirement are prices, in particular given that our measure of energy efficiency is the quotient between energy expenditures and total sales, both price-dependent. We start by discussing this potential source of bias. Unfortunately, the level of disaggregation in available producer price indices for the Mexican context is lower than the level of disaggregation in our industry-level fixed effects. Given that we already control for industry-year effects in all the analyses, using existing price indices cannot address this potential concern.

However, during our study period, gas and other oil derivatives' prices were constant within states, as PEMEX, a government-owned firm, was the only existing one in the industry. While some differences in prices across states existed (aimed at avoiding cross-border shopping), within each state, oil and gas prices were fixed each year by PEMEX. Electricity prices were determined differently as there was more than one provider at the national level. However, the existing electricity providers in the country had monopoly power at the state level, and prices were constant across industries within each state. The inclusion of state-year fixed effects should then control for changes in our outcome variable driven by changes in energy prices.

Changes in output prices, however, may indeed vary differentially across industries during our study period. The direction of the bias induced by this potential confounding factor depends then on the correlation between changes in tariffs and changes in output prices.[26] However, this correlation is very likely positive: output prices must decrease when output tariffs are reduced.[27] Recalling that our measure of energy efficiency is the quotient between energy expenditures and sales, in face of a drop in output prices, all else constant, we would observe an increase in the dependent variable, as only the denominator will be lower. Our results show that when tariffs decrease, energy expenditures over sales decrease. We then argue that the potential bias induced by the potential correlation between changes in tariffs and output prices is, if anything, biasing our results towards zero.

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[26] The Industrial Organization literature, for example, De Loecker and Warzynski (2012) and De Loecker et al. (2016) study how changes in input tariffs affect mark-ups independently of quantity. One implication of this literature is that caution should be taken when interpreting the results when researchers do not have information on quantity and price separately.

[27] Columns (1) and (2) in Table 5 show that the output tariff reductions decreased the values of total sales and domestic sales of plants. This is consistent with a positive correlation between output tariffs and prices.

5.1.2. Other types of tariffs

Nonetheless, while the changes in output prices driven directly by import tariffs are not likely to induce the results presented in this paper, changes in output prices driven by other forces may bias our estimates, to the extent that these forces can be correlated with output tariff changes. In order to explore if this is indeed the case, we run our main specification including a larger set of controls, which could arguably be correlated with both output tariffs and prices. In particular, we run the same specification, this time additionally including input tariffs, average Mexican tariffs on products firms use as inputs, and the average US tariffs Mexican firms would face if they exported their products to the US, as controls. In particular, we run regressions of the following form:

$$Y_{ijt} = \beta_1 Output\ Tariff_{it} + \beta_2 Input\ Tariff_{it} + \beta_3 US\ Tariff_{it} + (\gamma X_{it}) + \lambda_i + \mu_{jt} + \epsilon_{ijt} \tag{5}$$

where $Input\ Tariff_{it}$ denotes the input tariff on plant i at time t, which was constructed in the same way as the output tariffs in the previous sections and $US\ Tariff_{it}$ denotes US tariffs on goods produced by plant i at time t. Plant-level control variables include employment, export ratio, and total sales and capital.

In this framework, β_1, still captures changes in the dependent variables in response to changes in the output tariff, and can be interpreted as (the inverse of) the effect of import competition. β_2 captures the effect of changes in the input tariff, interpreted as (the inverse of) the effect of increased access to imported intermediate products. Finally, β_3 measures the effect of changes in the US tariff that plants would face if they exported, and can be interpreted as (the inverse of) the effect of export market access.

Appendix Table A.1 shows the results of these regressions for the two plant-level dependent variables analyzed in previous sections, i.e. energy efficiency, environmental and energy investment. The magnitude of the coefficients on the output tariff stays roughly the same as in the previous specifications and is still significant. Therefore, the results we have been putting forth do not appear to be driven by other changes occurring during the same time period, such as increased access to imported intermediate products and increased access to export markets. Appendix Table A.2 shows the results of these regression for the AOD measure. Again, our results are robust to inclusion of the other types of tariffs.[28]

It is perhaps worth stressing that our main results (presented in the previous section) do not include input and US tariffs as control variables, since input tariffs are found to be correlated with plants' characteristics and thus are very likely to not be exogenous (Teshima (2010)). Furthermore, for the sample analyzed, the effects of input tariff and US tariff reductions are not likely strong, as they would affect only the subset of plants that are using imported intermediate products or exporting.

5.1.3. Endogeneity of tariffs

A second potential concern is that industry characteristics may be correlated with tariff changes. Kowalczyk and Davis (1998), however, show that tariff reductions due to NAFTA were driven by U.S. interests, and not those of Mexican firms. In order to provide further evidence that this is not an important concern in our setting, Teshima (2010) provides evidence of no relationship between plant characteristics in 2000 and the subsequent output tariff reductions within an industry. Another potential misspecification issue is related to the timing of the plants' response to tariff changes. The extent to which tariff changes are expected by plants in our dataset, and that plants may react in advance to these expected changes, the relationship between environmental outcomes and contemporaneous tariff changes presented in this paper may fail to measure the relationship we seek to analyze.

In order to explore if plants responded to expected, not current tariff changes, and more generally, to indirectly test the validity of our empirical strategy, we would ideally show that there were no differential background trends in the outcomes of interest between plants who faced decreasing output tariffs and those who did not. Unfortunately, the characteristics of the dataset exploited do not allow us to fully perform this test, as the information on abatement expenditures as well as AOD is only available for the survey rounds included in the main results. Nonetheless, we can effectively test for differential pre-trends in energy efficiency and other potentially relevant characteristics as information on energy expenditures and other potentially relevant plant-characteristics are available from the EIA. In order then to test whether the changes in tariffs from 2000 to 2003 are correlated with changes in these outcomes before the changes in tariffs effectively took place, we run a series of regressions of the following form:

$$\triangle Y_{ij1997-2000} = \beta_1 \triangle Output\ Tariff_{ij} + \beta_2 \triangle Input\ Tarff_{ij} + \beta_2 \triangle US\ Tariff_{ij} + \mu_j + \epsilon_{ij} \tag{6}$$

Table 4 shows the results. As opposed to our main results, the coefficients of interest are small and insignificantly different from zero, suggesting that the parallel trends assumption in our diff-in-diff setting holds.

5.2. Mechanisms and interpretations

Throughout the text, we speculate that the reduction in tariffs reduced abatement expenditures and increased energy efficiency due to the fact that tougher competition may have induced firms to upgrade their technology and, as a side-result, decrease their emissions, reducing the need for directly investing in abatement efforts. We do not measure technology or emissions directly. As a result, we are aware that the exploration of the precise mechanisms through which the effects found can be explained is a very difficult task, and that our interpretation is not the only potential explanation of our findings. Nonetheless, several key facts make us relatively confident that this is the most likely explanation for the effects found.

In order to shed better light on the potential mechanisms behind the effects found, Table 5 shows the regression results when investment in process R&D, sales and health investments are used as dependent variables.

5.2.1. Technology and scale effects

First, we find an impact of tariff changes on investment in process R&D, replicating the results of Teshima (2010) in our sample. Columns (3) and (4) of Table 5 show the results. Thus, we find evidence consistent with our hypothesis that output tariff reductions induced plants to upgrade technology in their production process.

As shown in Columns (1) and (2) of Table 5, tariff reductions are associated with a decrease in the value of sales. While we cannot identify whether this decrease is due to prices or quantities, the extent to which it may be driven by a decrease in production is an important concern for the interpretation of our findings, as another potential mechanism behind the observed increase in energy efficiency may be related to a change in scale.

Our main results, however, suggest that the increase in energy efficiency is driven by both a decrease in electricity and fuel expenditures over sales. We believe that existing installed capacity is very unlikely to be affected by tariff changes in the short term, as it may require substantial capital investments. Fuel is likely used mainly to power the

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[28] A reader may wonder why input tariff reductions have the same sign as output tariffs. We believe that the results on input tariff (reductions) are consistent with our general technology upgrading hypothesis. Trade literature emphasizes that the reduction in input tariffs allow domestic firms to buy more cheaply foreign intermediate products that embody foreign better technology, and thus to do more technology upgrading and innovation (see for example Goldberg et al. (2010). Furthermore, Amiti and Konings (2007) find both output tariff reductions and input tariff reductions increase plant-level TFP. Our results are consistent with these findings.

Table 4
Correlations between the changes in initial sales and employment and changes in tariffs, EIA-SIEM panel 1997–2003[a].

	(1) $\triangle$Log Total Sales	(2) $\triangle$ Log Domestic Sales	(3) $\triangle$Exporter Dummy	(4) $\triangle$Log Exports	(5) $\triangle$Log Employment	(6) $\triangle$Log TFP	(7) $\triangle$Energy Efficiency
Output Tariff Changes	0.0103	0.0088	−0.0012	−0.0157	−0.0100	−0.0015	0.0032
	(0.0111)	(0.0134)	(0.0025)	(0.0244)	(0.0232)	(0.0087)	(0.0047)
Input Tariff Changes	0.0058	0.0133	−0.0112	−0.0123	−0.0122	−0.0110	−0.0011
	(0.0088)	(0.0145)	(0.0108)	(0.0241)	(0.0223)	(0.0321)	(0.0043)
US Tariff Changes	0.0067	0.0059	0.0023	0.0234	−0.0136	0.0052	−0.0055
	(0.0114)	(0.0137)	(0.0052)	(0.00355)	(0.0189)	(0.0102)	(0.0048)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	625	625	625	416	625	625	625
R^2	0.335	0.336	0.242	0.259	0.318	0.143	0.132

[a] Notes: The table reports coefficients on the changes from 2000 to 2003 in output tariffs, input tariffs and U.S. tariffs from plant-level regressions of the changes in plant characteristics from 1997 to 2000 on the changes in these tariffs and industry effects. TFP is estimated using Olley-Pakes method. Plant-level output tariff for a plant is the simple averages of the product-level tariffs of the products that the plants produce. Similarly, the plant-level input tariff for a plant is the simple averages of the product-level tariffs of the products that the plant uses as intermediate products. The plant-level U.S. tariff for a plant is the simple averages of the U.S. tariffs for U.S imports from Mexico of the products that the plants produce. Robust standard errors in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

Table 5
Regressions of other outcome variables on tariffs, ESIDET-EIA-SIEM panel 2000–2003[a].

Dependent Variable	(1) Log Total Sales	(2) Log Domestic Sales	(3) Process R&D Intensity	(4) Process R&D Dummy	(5) Health Investment Intensity	(6) Health Investment Dummy
Output Tariff	0.0125*	0.0164**	−0.0224*	−0.0107*	−0.0022	−0.0065
	(0.068)	(0.0080)	(0.0123)	(0.0066)	(0.0032)	(0.0052)
Input Tariff	−0.078	−0.0053	0.0135	0.0007	0.0035	0.0079
	(0.0079)	(0.0879)	(0.0082)	(0.0034)	(0.0027)	(0.0082)
US Tariff	−0.0032	0.0015	−0.0152	−0.0027	−0.0033	−0.0100
	(0.0031)	(0.0027)	(0.0111)	(0.0024)	(0.0029)	(0.0101)
Plant fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Region-year effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1776	1776	1776	1776	1776	1776
R^2	0.06	0.04	0.16	0.20	0.14	0.13

[a] Notes: The table reports coefficients on the output tariffs, the input tariffs, and the U.S. tariffs from plant-level regressions of various variables on these three tariffs, plant fixed effects, industry-year fixed effects and state-year fixed effects. $Log\ Process\ R\&D_{it} = log(Process\ R\&D_{it} + 1)$, abd $Log\ Health\ Investment_{it} = log(Health\ Investment_{it} + 1)$. Plant-level output tariff for a plant is the simple average of the product-level tariffs of the products that the plants produce. Similarly, the plant-level input tariff for a plant is the simple average of the product-level tariffs of the products that the plant uses as intermediate products. Similarly, the plant-level U.S. tariff for a plant is the simple average of the product-level tariffs of the products that the plant would face if they export to the U.S. Robust standard errors in parentheses. Significance: * 10 percent, ** 5 percent, *** 1 percent.

existing machinery, which remains unchanged. Fuel use per unit of output is then very unlikely to decrease in face of a decrease in production in the context analyzed. Electricity, however, may be used to power machinery, but is also likely to vary with respect to total employees and other more flexible production inputs. If our results were driven by a scale reduction, we would then expect the decrease in fuel per unit of output to decrease in a smaller magnitude than electricity per unit of output, which is not the case in the context of our study. We then argue that the results presented in the main paper are unlikely driven by a change in scale.

Furthermore, for each industry, the correlation between the 2000–2003 changes in sales and changes in energy expenditure divided by sales within industry is rather small. The mean of the correlation coefficient is 0.03. Less than 10% of the industries have a correlation coefficient lower than −0.2. Thus, it appears to be the case that the extent to which changes in sales mechanically drive our results on the changes in energy efficiency is limited.

5.2.2. Abatement expenditure as luxury goods

Both environmental and energy investment might be carried out as a form of Corporate Social Responsibility (CSR) activities or luxury expenditures from the part of firms. If so, competitive pressure may leave less room for such activities. If incentives for plants to spend on abatement are mainly driven by altruism, and if overusing electricity can to some extent be some form of luxury (such as turning the lights on when unnecessary) an increase in competition could reduce plants' profits and, as a consequence, decrease abatement expenditures and increase energy efficiency. Thus, the negative effects of increased competition on environmental and energy investments found in this paper could therefore be a result of reduction in CSR activities, not because of substitutability between such investment and general technology. This alternative hypothesis cannot fully explain why then the energy efficiency and pollution measures could improve. Nonetheless, we provide one more piece of evidence against this alternative explanation. We run regressions estimating the effects of the changes in the three types of tariffs on health investment. Our idea is that if environmental investment decreased after an increase in competition because of the reduction of CSR activities, then we should also see the negative effect of competition on other types of social investment. Columns (5) and (6) of Table 5 show that there are no significant effects of any tariffs on health investment and that the coefficients on output tariffs have the opposite sign to those found for environmental and energy investment. While we understand that this test does not fully address this potential issue, we believe it is suggestive evidence that a decrease in luxurious expenditures is not the main driver of the decrease in abatement expenditures as a result of output tariff reductions.

5.2.3. Additional results

Finally, in the online appendix, we present evidence suggesting that (a) an endogenous regulatory response is not likely driving our main results, (b) exit due to tariff reduction would not wholly explain our results on AOD, and (c) the results on AOD are not likely biased due to spatial spillover effects.

6. Conclusion

We have found evidence that the reduction of tariffs on the goods produced by Mexican plants is associated with improved energy efficiency, reduced air pollution near plants' location, but also reduced specific environmental and energy investment. This suggests that import competition induced by trade liberalization indirectly affected the environment positively, through the plants' incentive to change their energy efficiency through general technological investment. This effect would have been difficult to identify by solely analyzing the environment and energy investment measures. The findings illustrate the importance of analyzing the three related measures at the same time, opposed to relying on the assumption that environment and energy investment is positively correlated with environmental performance. In the setting analyzed in this paper, this assumption could lead researchers to incorrectly conclude that import competition damages the environment.

While focusing on a very specific policy change apparently unrelated to environmental regulations, our results are informative to the literature that measures the effect of different policies on environmental outcomes- Our results show that even when detailed data at the plant level are available, caution should be taken when trying to measure the effects of policies on environmental performance. In our setting, one would have been tempted to conclude that import competition affects the environment negatively if the plant-level environmental investment measure had been the only available variable. Firms often make direct investments in reducing emissions to comply with environmental regulation that caps these emissions. However, since trade has effects not only on the incentives to pollute but also on the adoption of different technologies (which may already be more efficient and less polluting), the direct investment in reducing emissions can decrease. It is then necessary to obtain data both on plants' direct investment in pollution abatement and on environmental performance in general, in order to better understand the relationship between output price (driven in this case by trade openness), technology adoption, and the aggregate effect of both on pollution emissions. This message generally applies to any evaluation of the determinants of environmental performance.

We acknowledge the limitations of our analysis, though we have discussed how we could rule out alternative hypotheses. First, our plant-level measures may not correspond perfectly to abatement and technology upgrading. An analysis of separate industries may find more concrete examples of abatement and general energy-saving technology in a more precise way. In addition, a dataset with information on price and quantity separately for both output and energy would allow researchers to estimate energy efficiency more accurately. These would enable researchers to better assess the relative importance of abatement and technology and their impact on environmental outcomes in developing countries.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jdeveco.2017.11.004.

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