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Pollution havens: International empirical evidence using a shadow price measure of climate policy stringency

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Abstract

Given the ambiguous empirical results of previous research, this paper tests whether support for a climate policy induced pollution haven effect and the pollution haven hypothesis can be found. Unlike the majority of previous studies, the analysis is based on international panel data and includes several methodological novelties: By arguing that trade flows of dirty goods to less polluting sectors may also be influenced by changes in policy stringency, trade information on primary, secondary, and tertiary sectors are included. In order to clearly differentiate between dirty sectors and sectors with high pollution abatement costs, separate measures for pollution intensity and policy stringency are implemented. For the latter an internationally comparable, sector-specific measure of climate policy stringency is derived using a shadow price approach. Endogeneity between a country's trade openness and its trade flows is addressed by estimating a gravity-based instrumental variable.

The results provide evidence for a stronger pollution haven effect regarding carbon dioxide intensive and emission relevant energy intensive sectors. However, the impact of climate policy on polluting sectors seems to be rather limited as a distinct pollution haven effect for gross energy intensive sectors cannot be found. Similarly, no support for the stronger pollution haven hypothesis is revealed.

Keywords

International trade; competitiveness; pollution haven; global pollution; environmental policy stringency; shadow price; gravity equation

1 Introduction

As some countries implement stricter environmental policies than others, it is feared that the domestic production of dirty goods is either reduced or moved to countries with less strict mitigation policies, so-called pollution havens, implying a loss in competitiveness for the more regulated countries. Of particular interest in this discussion are the potential adverse effects of climate policy in specific and along with that reservation that unilateral climate policy regulation may not be effective in cutting total greenhouse gas emissions.¹

Copeland and Taylor (2004) distinguish between a pollution haven effect and the stronger pollution haven hypothesis.² On the one hand, according to the pollution haven effect net exports of dirty goods from highly regulated countries should decline as a more stringent regulation entails a specialization of a country in the production of cleaner goods. In *figure 1* this effect is highlighted and connected to the issue of greenhouse gas emissions for the energy intensive metals industry for a set of 28 countries.³ Here, the shadow price of emission relevant energy is used to measure the stringency of climate policy.⁴ The figure suggests that the metals industry in countries with a higher shadow price, i.e. stricter climate policy, tended to experience larger declines in net exports per value added along with smaller increases or even reductions in carbon dioxide emissions per value added. On the other hand, the pollution haven hypothesis postulates that trade liberalization will shift polluting industries from countries with a relatively stringent regulation to countries with a relatively weak regulation. While some support for the pollution haven effect has been found (Ederington and Minier 2003; Levinson and Taylor 2008), so far no compelling support for the pollution haven hypothesis has been detected (Cole and Elliot 2003; Levinson 2009).

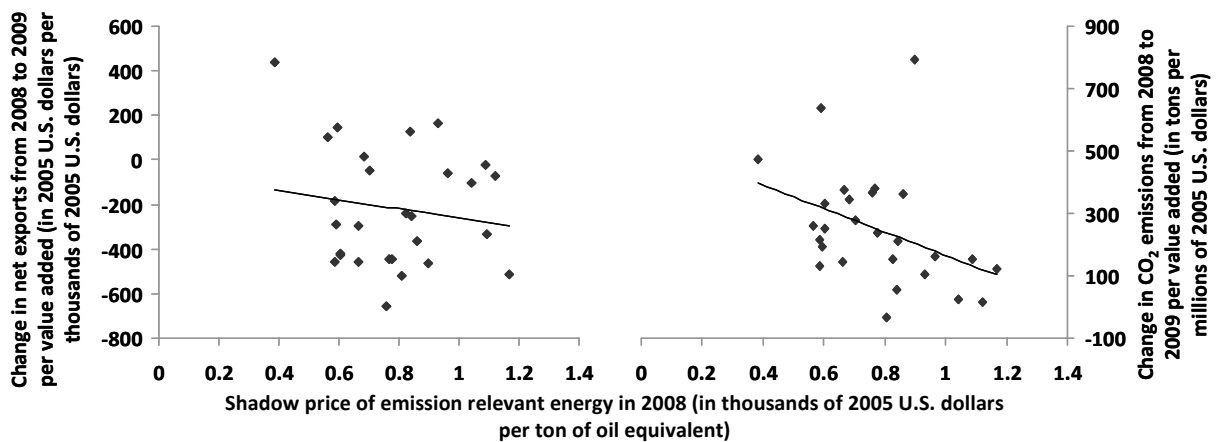


Figure 1: Change in relative CO₂ emissions and net exports for different levels of climate policy stringency for the basic metals and fabricated metals sector for a set of 28 countries (including a linear trend)

However, existing literature on pollution havens lacks several shortcomings: Only few empirical work tests the pollution haven hypothesis compared to the large number of papers on the pollution haven effect (Copeland 2011); the same holds true with regards to empirical research specifically on pollution havens for global pollutants vs. the broad body of literature on local pollutants (Bao et al. 2011; He 2006); most papers employ U.S. data or are mainly

¹ In the context of climate policy and pollution havens the literature commonly refers to the issue of carbon leakage (Aldy and Pizer 2011; Frankel 2009).

² Likewise, Ederington et al. (2004) distinguish between a direct and an indirect effect.

³ A detailed overview of the included countries can be found in *table 1*.

⁴ This paper uses a closely related measure to determine the stringency of climate policy. Section 4.2 introduces the estimation procedure of the shadow price approach.

single country studies (Keller and Levinson 2002; Wagner and Timmins 2009); and only few studies use panel data sets with sound measures of policy stringency (Copeland 2011).

For these reasons, this paper will extend Ederington et al.'s (2004) approach to test for both the pollution haven effect and the hypothesis with regards to the impact of climate policy stringency on trade flows. Using international panel data econometric concerns are accounted for by utilizing a consistent, internationally comparable, sector-specific shadow price measure of climate policy stringency as well as an instrumental variable for a country's trade openness. A relatively large set of 28 OECD⁵ countries consisting of developed countries, newly industrialized countries, and former transition economies is analyzed for the years 1995 to 2009. Unlike previous research the paper takes into account that dirty goods are also used as inputs in less polluting sectors and includes not only industry sectors, but 33 primary, secondary, and tertiary sectors. Dirty sectors are identified with the help of carbon dioxide emission intensities as well as emission relevant energy and gross energy intensities.⁶ Thus, both the research on pollution havens for global pollutants is furthered and the practice of treating sectors with high pollution abatement costs as dirty is unleashed. This paper provides evidence for a distinct climate policy related pollution haven effect regarding carbon dioxide intensive and emission relevant energy intensive sectors. Yet, the impact of climate policy seems to be limited to sectors with high global pollution emissions, because no effect on trade flows is revealed for mere gross energy intensive sectors. Moreover, no support for the stronger pollution haven hypothesis can be found.

In the next section a literature review on empirical results concerning the pollution haven effect and the hypothesis is given. The used data is introduced in section 3. Section 4 subsequently describes the used methodology of the applied pollution haven model, the shadow price measure of climate policy stringency, and a gravity-based instrument for trade openness to avoid problems of endogeneity. The results of the two-stage least squares (2SLS) estimator are provided and discussed in section 5 and section 6 concludes.

2 Literature review

While Jaffe et al. (1995) review early literature on pollution havens, an update including more recent work is, for instance, given by Brunnermeier and Levinson (2004) and Copeland (2011). In the next two subsections the concepts of and previous empirical literature on the pollution haven effect and hypothesis are detailed.

2.1 Pollution haven effect

Pollution haven effect models analyze to what extent the stringency of environmental policy influences economic activity. The intuitive idea is that environmental regulation increases the costs of key inputs for goods with pollution intensive production, which in turn decreases the jurisdiction's comparative advantage in those dirty goods. Given that the cost increases are relatively high the pollution haven effect predicts changed patterns of trade or

⁵ OECD is short for Organisation for Economic Co-operation and Development.

⁶ Following the definition in the World Input Output Database (WIOD) the difference between gross energy use and emission relevant energy use is that the latter excludes the non-energy use, e.g. asphalt for road building, and the input for transformation, e.g. crude oil transformed into refined products, of energy commodities. While gross energy use is directly linked to expenditures for energy inputs, emission relevant energy use directly relates energy use and energy-related emissions.

production relocations. In order to test this, early econometric studies generally use a reduces-form regression for a cross-section of manufacturing or industry sectors i (Tobey 1990):

$$(1) \quad M_i = \beta_1 \lambda_{E,i} + X_i' \delta + \varepsilon_i$$

Thereby, M is a measure of economic activity, λ_E is a measure of regulatory stringency, X is a vector of control variables such as Heckscher-Ohlin variables or factor endowments, and ε is the error term. In previous research three types of measures of economic activity have been commonly used, namely net exports or net imports, foreign direct investments, and the share of pollution intensive goods production (Jaffe et al. 1995). This paper will focus on the effect of policy stringency on trade. Consequently, a positive and significant coefficient $\hat{\beta}_1$ provides evidence for the presence of a pollution haven effect when net imports are used as the measure of economic activity.⁷

There exists a comparatively large body of literature on the pollution haven effect. Overall, the early research using cross-sectional data tends to find no proof for a pollution haven effect and some studies even find the opposite, i.e. industries facing relatively high pollution abatement costs are leading exporters (Grossmann and Krueger 1993; Kalt 1988; Levinson 1996). However, these studies are unable to control for unobserved heterogeneity across sectors or firms and may face problems of endogeneity and data aggregation (Levinson and Taylor 2008). With the intention of taking heterogeneity into account more recent research uses panel data and adds industry- and time-specific fixed effects, which are denoted η_i for sector i and η_t for year t respectively.⁸

$$(2) \quad M_{it} = \eta_i + \eta_t + \beta_1 \lambda_{E_{t-1},it} + X_{it}' \delta + \varepsilon_{it}$$

Studies following this approach without taking the potential endogeneity issue into account present mixed results regarding the impact of environmental regulation on trade flows (Harris et al. 2002; Mulatu et al. 2004; van Beers and van den Bergh 2003). Yet, by neglecting that economic activity and environmental regulation may be simultaneously determined the estimated effects may be downward biased.⁹

Research using both panel data and instrumental variables to account for simultaneity provides growing support for the pollution haven effect. As one of the first articles Ederington and Minier (2003) address the possible endogeneity problem and reveal significantly larger pollution haven effects for the U.S. manufacturing sectors between 1978 and 1992 when instrumental variables are employed. Similarly, Levinson and Taylor (2008) find a consistently larger effect for the U.S. industry sectors' trade with Canada and Mexico

⁷ The pollution haven effect is measured as the first partial derivative of the economic activity M with respect to the environmental policy stringency λ_E , i.e. $\partial M / \partial \lambda_E = \beta_1$. Hence, a positive and significant coefficient $\hat{\beta}_1$ implies, ceteris paribus, that increasing the policy stringency results in larger net imports.

⁸ As a time dimension is now added to the data, empirical studies often lag the regulatory stringency measure λ_E to see whether strict environmental regulation in the previous period results in changed economic activity (Cole and Elliott 2003).

⁹ An endogeneity problem may arise, because the pollution haven effect predicts that environmental regulation influences the economic activity such as trade. However, the opposite may also be true. For instance, trade can increase income, which in turn may raise voters' demand for the normal good environmental quality and the desire for a stricter environmental regulation. Alternative explanations for the downward bias are given by Ederington et al. (2005), who show that the estimated pollution haven effects become larger when distinguishing between industrialized and developing countries and accounting for transportation costs.

between 1977 and 1986 for their two-stage least squares estimates compared to the fixed effects estimates. Further U.S. evidence for the pollution haven effect is provided by Ederington et al. (2004), who analyze panel data from 1978 to 1994. Following an analogous approach for Germany Althammer and Mutz (2010) find a significant pollution haven effect for the industry sectors for the time period 1995 to 2005. However, no support is found between 1977 and 1994 even after the data is split between trade with OECD and non-OECD countries.

2.2 Pollution haven hypothesis

The pollution haven hypothesis claims that trade liberalization disproportionately influences trade in polluting goods and causes polluting industries to relocate to countries with weak environmental regulation. In order to test this, the variable trade openness TO and an interaction term between trade openness and the average environmental policy stringency are added to equation (2):¹⁰

$$(3) \quad M_{it} = \eta_i + \eta_t + \beta_1 \lambda_{E,t-1,it} + \beta_2 TO_{it} + \beta_3 \bar{\lambda}_{E,i} TO_{it} + X'_{it} \delta + \varepsilon_{it}$$

The specification deliberately includes the average environmental policy stringency for every sector i to test if changes in trade openness have a larger impact on the economic activity M for industries facing relatively higher pollution abatement costs (Ederington et al. 2004). In contrast to that the interaction with the general environmental policy stringency λ_E tests for effects on the economic activity for industries whose pollution abatement costs increased relatively more. Consequently, in the case of net imports as the measure of economic activity M the coefficient $\hat{\beta}_3$ needs to be positive and significant to provide support for the pollution haven hypothesis.¹¹

There exists little empirical work that tests the pollution haven hypothesis compared to the pollution haven effect. Overall, the results of these papers tend to be inconsistent with the pollution haven hypothesis and, therefore, provide no convincing support. Levinson (2009) finds that U.S. imports have become less pollution intense relative to U.S. exports between 1972 and 2001. This confirms earlier research for the time period 1978 to 1994 by Ederington et al. (2004), who in addition show that pollution intensive U.S. manufacturing sectors are less responsive to tariff reductions than clean ones. The empirical evidence using non U.S. data is similar. For Germany Althammer and Mutz (2010) estimate no significant interaction effect between the tariff rate and environmental regulation for both time periods 1977 to 1994 and 1995 to 2005. With the help of an input-output analysis of India's trade in the years 1991/92 and 1996/97 Dietzenbacher and Mukhopadhyay (2007) also find no evidence for pollution havens in connection with trade liberalization. The composition effect of trade liberalization on emission intensities is analyzed by Cole and Elliott (2003), who use emissions data of 32 countries. Instead of a negative relationship as proposed by the pollution haven hypothesis, their paper reveals no relationship between lagged income

¹⁰ Instead of the variable trade openness research also commonly uses a measure of trade barriers, such as tariff rates, in order to determine the level of trade liberalization (Althammer and Mutz 2010; Ederington et al. 2004).

¹¹ The pollution haven hypothesis is given by $\partial^2 M / (\partial TO \partial \bar{\lambda}_E) = \beta_3$. If the coefficient $\hat{\beta}_3$ is positive and significant this implies that an increase in trade openness leads to larger increases in net imports for industries facing relatively higher environmental policy stringencies. As in equation (1) and (2) the pollution haven effect is still determined by $\partial M / \partial \lambda_E$.

per capita and the country-specific trade elasticities of carbon dioxide and biochemical oxygen demand.

As will be argued and tested in section 4.3 problems of endogeneity may arise not only for the measure of environmental regulation, but also for the variable trade openness. However, to the author's knowledge so far no empirical research on the relationship between trade liberalization, environmental regulation, and trade flows addresses this issue with the help of an additional instrumental variable for trade openness.

3 Data

In order to analyze both the pollution haven effect and the hypothesis two international panel datasets are compiled.

The main dataset including sector-specific information is used for the pollution haven model and the estimation of the shadow price measure of climate policy stringency. As the main data source the World Input Output Database (WIOD) is used. Complementary energy price and capital investment data, which is needed for the shadow price estimation, is obtained from the International Energy Agency and the Penn World Tables respectively. The OECD provides exchange rates and country-specific price indices.

With the exception of the energy price and the capital investment data, only existing variables from the WIOD are used. Emission relevant energy prices are estimated following Althammer and Hille (2013), who determine sector-specific prices based on a weighted average of the prices of seven energy carriers and the overall price development. The sector-specific capital stock data is constructed by applying the perpetual inventory method as explained in Caselli (2005) and disaggregating the country-level estimates using the sector's shares in the total national capital stock as given in the WIOD.¹² In general, all monetary variables are converted from basic prices in local currency to 2005 U.S. dollars with the help of the exchange rates as well as country- and sector-specific deflators. Given that misdirecting incentives for investors or plant owners are analyzed, prices are not calculated in purchasing power parities.¹³

The final main dataset is comparatively large and covers sector-specific information on 33 primary, secondary, and tertiary sectors for a set of 28 OECD countries from 1995 to 2009. The sectors and countries are in correspondence with the structure of the main data source WIOD.¹⁴ Because of the limited data coverage on energy prices and capital stocks, several countries from the original database as well as the air transport and the private households sector with employed personal have to be excluded. A list of the included nations is provided in *table 1*. Not only developed countries, but also newly industrialized countries like Mexico and Turkey and former transforming economies from Eastern Europe are included. Hence, the dataset allows testing for the existence of pollution havens on an international basis and includes the effects of the opening of former Eastern Bloc countries along with the implementation of the Kyoto protocol.

¹² The WIOD data is not used directly, because capital stock information is not provided for the years 2008 and 2009 and extrapolating the data using prior growth rates seems problematic given the potential negative consequences of the world financial crisis starting in 2008.

¹³ The final variables of both datasets and their units of measurement can be found in *table 6* in appendix 1.

¹⁴ *Table 7* in appendix 2 provides an overview of the 33 included sectors. The sectors are structured using the division-level ISIC Rev. 3.1.

Country overview pollution haven model (in total 28 countries)	Additional countries included in the trade openness instrument estimation (in total 12 countries more)
Asia and Oceania (4 countries) Australia, Japan, Korea, Turkey	(+4 countries) China, India, Indonesia, Taiwan
Americas (3 countries) Canada, Mexico, United States	(+1 country) Brazil
East and Southeast Europe (7 countries) Czech Republic, Estonia, Greece, Hungary, Poland, Slovak Republic, Slovenia	(+6 countries) Bulgaria, Cyprus, Latvia, Lithuania, Romania, Russia
Western Europe (14 countries) Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom	(+1 country) Malta

Table 1: Country overview

In addition, geographical country characteristics and information about the population size are required for the estimation of the gravity-based instrumental variable for trade openness. Given the limitation of the main dataset to 28 countries and the concurrent dependence of the instrument on a high explained share of bilateral trade flows, a second data set including all 40 countries in the WIOD is compiled. *Table 1* also provides an overview of the additional included countries, comprising nations such as the BRIC countries¹⁵. The second dataset includes country-specific information from 1995 to 2009. WIOD serves as the data source for the bilateral trade flows and the gross output, whereas these monetary values are converted as in the first dataset. The CIA World Factbook as well as the CEPII gravity dataset provide the data on geographical country characteristics such as the countries' area.¹⁶ The population size information is taken from the Penn World Tables.

4 Methodology

The data is used to test whether empirical evidence for the pollution haven effect and the hypothesis with regards to climate policy regulation exists. The estimation process is accompanied by the given difficulties in measuring policy stringency and trade openness, and the possible endogeneity of both. In the following the used methodology of the pollution haven model is introduced. Then, both a climate policy stringency measure and a trade openness instrument are estimated in order to cope with potential econometrical pitfalls.

4.1 Pollution haven model

The basic set-up for testing for the presence of pollution havens based on trade flows is introduced in section 2. This paper extends the approach to a multiple country environment and includes not only trade flows of industry sectors in the analysis, but of primary, secondary, and tertiary sectors:

¹⁵ The BRIC countries refer to Brazil, Russia, India, and China and were first framed by O'Neill (2001).

¹⁶ CIA abbreviates Central Intelligence Agency and CEPII is short for Centre d'Etudes Prospectives et d'Informations Internationales.

$$\begin{aligned}
(4) \quad \frac{NI_{ict}}{y_{ict}} = & \eta_i + \eta_c + \eta_t + \beta_1 \lambda_{E_{t-1}, ict} + \beta_2 TO_{ct} + \beta_3 \bar{\lambda}_{E, ic} TO_{ct} + \beta_4 \lambda_{E_{t-1}, ict} \frac{x_{E, it}}{y_{it}} \\
& + \beta_5 \bar{\lambda}_{E, ic} TO_{ct} \frac{x_{E, it}}{y_{it}} + \beta_6 \frac{CapComp_{ict}}{y_{ict}} + \beta_7 \frac{HSLabor_{ict}}{y_{ict}} \\
& + \beta_8 \frac{MSLabor_{ict}}{y_{ict}} + \beta_9 \frac{LSLabor_{ict}}{y_{ict}} + \varepsilon_{ict}
\end{aligned}$$

Net imports NI of sector i and country c in year t are used as the measure of economic activity. In order to adjust for the different sector sizes, gross values are divided by the sector's output y . As before, λ_E is the sector-specific climate policy stringency and TO is the country's trade openness. Dirty sectors are identified using average sectoral intensities of carbon dioxide emissions, emission relevant energy use, and gross energy use, which are each denoted by x_E/y . $CapComp$, $HSLabor$, $MSLabor$, and $LSLabor$ are sector-specific compensation for capital, high-skilled, medium-skilled, and low-skilled labor respectively and are in the form of capital and labor intensities used as control variables. Finally, η capture sector-, country-, and time-specific fixed effects and ε represents the error term.

Compared to equation (3) the country-specific fixed effects η_c are supplemented and, in particular, the additional coefficients β_4 and β_5 are estimated. While the former is demanded by the international dataset, the latter facilitates the differentiated analysis of dirty sectors in the multi-sectoral setting. Closely connected to the second issue are the methodological questions how regulatory stringency is measured and how dirty sectors are identified. Previous empirical research often measures sector's regulatory stringency λ_E as pollution abatement costs per total material costs or per value added (Cole and Elliot 2003; Ederington et al. 2004). The measure is then simultaneously used to determine dirty sectors implying that sectors with high abatement costs are pollution intensive sectors.¹⁷ Consequently, such papers analyze whether sectors facing high abatement costs experience changes in trade flows. However, also non-dirty sectors may use dirty goods as inputs and, thus, may as a consequence of tighter policy regulation and increased domestic prices import relatively more of the dirty goods.

This paper will test whether sectors facing strict climate policy regulation, in general, experience changes in trade flows and to what extent these impacts differ for pollution intensive sectors. For this purpose, a clear differentiation between strictly regulated sectors and dirty sectors is employed by changing both the unit of measurement of regulatory stringency and the identification of dirty sectors. On the one hand, the used shadow price measure of climate policy stringency, which is introduced in more detail in the next subsection, is measured in pollution abatement costs per unit of emission relevant energy use. This allows taking into account that clean sectors may face stricter regulation than dirty sectors in the form of higher prices for emission relevant energy use, while at the same time the dirty sectors' aggregate abatement costs may be comparatively higher.¹⁸ On the other hand, it becomes necessary to discriminate between dirty and non-dirty sectors, because the stringency measure does not automatically do that anymore. From an output perspective

¹⁷ Cole and Elliott (2003) reveal for U.S. industry sectors that pollution intensive sectors face high pollution abatement costs per value added and are relatively capital intensive.

¹⁸ For instance, in the case of the German support of renewable energies the costs are passed on to clean industries and consumers, whereas energy intensive firms are relieved from the financing and have to pay lower energy prices per kilowatt hour (Diekmann et al. 2012).

and in the context of climate change this paper classifies a sector as dirty if the average sectoral carbon dioxide emission intensity is relatively high. Likewise, from an input perspective a sector is dirty if its average emission relevant energy use intensity is relatively high. In order to test the reach of climate policy, the less restrictive average sectoral gross energy use intensity is added as a third identifier of dirty sectors. Using average sectoral values across the set of 28 countries acknowledges that some sectors are dirtier than others, whereas the same sector in different countries can have various pollution intensities, e.g. due to different available technologies and policy stringencies.

This clear differentiation between pollution and regulation facilitates the inclusion of non-industry sectors. In contrast to previous research that predominantly looks at industry or manufacturing sectors, the pollution haven model is analyzed using data on primary, secondary, and tertiary sectors. Hence, imports of potentially dirty goods to a larger number of less polluting sectors, like many service sectors, can be incorporated.

In order to analyze if changes in climate policy regulation have a larger impact on the net imports of pollution intensive sectors, the additional interaction terms with the average pollution intensity x_E/y are included in equation (4). Following the reasoning in section 2 evidence for dissimilarities between dirty sectors and other sectors concerning pollution havens is provided by the partial derivatives with respect to the pollution intensity. In specific, the pollution haven effect is given by $\partial^2(NI/y)/(\partial(x_E/y)\partial\lambda_E)$ and the pollution haven hypothesis is provided by $\partial^3(NI/y)/(\partial(x_E/y)\partial TO\partial\bar{\lambda}_E)$.¹⁹ Thus, positive and significant coefficients $\hat{\beta}_4$ and $\hat{\beta}_5$ provide respective evidence for a stronger impact of climate policy regulation regarding the pollution haven effect and hypothesis for pollution intensive sectors. The coefficients β_1 and β_3 , which are used in equation (3) to test for pollution havens, as well as the coefficient β_2 are kept in the final specification (4) to control for general impacts of climate policy stringency and trade openness on the net imports of all sectors.²⁰ Given the utilization of an instrumental variable for trade openness, the two-stage least squares estimator is applied to estimate equation (4).

4.2 Shadow price measure of climate policy stringency

Quantifying the regression coefficients in equation (4) requires a measure of the stringency of environmental regulation in general and climate policy in specific. Brunel and Levinson (2013) group and evaluate the existing measurement approaches. They come to the conclusion that the majority of the used approaches in empirical literature face conceptual problems or have a limited applicability. The internationally comparable shadow price measure of climate policy stringency developed by Althammer and Hille (2013) determines regulatory stringency based on sector-specific emission relevant energy costs and overcomes several of the shortcomings of the existing approaches.²¹ At the same time, the weaknesses of the measure are predominantly owing to the nature of shadow price

¹⁹ As before, the impact of the lagged regulatory stringency determines the pollution haven effect and the pollution haven hypothesis is analyzed based on the impact of the sector- and country-specific but time-invariant average regulatory stringency.

²⁰ Given that additional country-specific fixed effects and an instrumental variable for the country-specific trade openness are included, the individual effect of trade openness on net imports is expected to be insignificant. In section 4.3 more information is provided on the reasoning.

²¹ See Althammer and Hille (2013) for a detailed overview of the strengths of the shadow price approach and of measures of environmental and climate policy stringency.

approaches in general, namely the dependence on the selected functional form of the cost function and the use of cost data for existing firms. Therefore, this paper will follow Althammer and Hille (2013) and estimate the differences between the shadow prices of emission relevant energy and the respective market average stringencies as the consistent measure of climate policy stringency.

In order to indirectly estimate firm's or sector's pollution abatement costs, the shadow price approach makes use of microeconomic theory and the choices made by corporation revealing their profit maximizing behavior. The shadow price of a polluting input is, *ceteris paribus*, defined as the potential reduction in outlays spent on other variable inputs, which can be realized by using an additional unit of the polluting input (van Soest et al. 2006). In other words, if the price for a polluting input is relatively low, like in the case of no regulation, than it is beneficial for firms to increase the use of the polluting input so that total expenditures decrease. In the case of a more stringent regulation the price for the polluting input is relatively higher and firms will use less of the polluting input (Brunel and Levinson 2013). Hence, climate policy drives a wedge λ_E between a corporation's or the sector's shadow price Z_E for an additional unit of the polluting input E and its undistorted market price p_E (Morrison Paul and MacDonald 2003; van Soest et al. 2006):²²

$$(5) \quad Z_{E,ict} = \alpha_E p_{E,it} + \lambda_E D_{ict}$$

As the wedge λ_E and the shadow price Z_E summarize the hidden effects of all direct and indirect regulations both can serve as a measure of policy stringency (Althammer and Hille 2013). While a positive wedge and a comparatively high shadow price indicate a restrained usage of the polluting input and higher abatement costs compared to the market average, a negative wedge and a comparatively low shadow price are a sign for a subsidized usage. Thus, the wedge is a pure measure of differences in policy stringency and the shadow price includes overall market changes in stringency.

The shadow prices along with the wedges are determined by estimating a firm's or a sector's cost function based on the revealed behavior, i.e. the levels of output and the prices as well as quantities of the inputs, except for the price of the polluting input. This paper applies Morisson's (1988) Generalized Leontief variable cost function to two variable inputs. After assuming long-run constant returns to scale (Morisson 1988) and insignificant time trends (van Soest et al. 2006) the variable cost function C reads as follows:

$$(6) \quad C_{ict} = y_{ict} [\alpha_{LL} p_{L,ict}^{0.5} + \alpha_{LE} p_{L,ict}^{0.5} Z_{E,ict}^{0.5} + \alpha_{EE} Z_{E,ict}^{0.5}] + \alpha_{LK} y_{ict}^{0.5} p_{L,ict} x_{K,ict}^{0.5} \\ + \alpha_{EK} y_{ict}^{0.5} Z_{E,ict} x_{K,ict}^{0.5} + \alpha_{KK} p_{L,ict} x_{K,ict}^{0.5} + \alpha_{KK} Z_{E,ict} x_{K,ict}^{0.5}$$

Here, y is the output, p_L is the price of the fully variable input labor L , and Z_E is the shadow price of emission relevant energy E , the variable input where e.g. due to climate regulation the shadow price may be different to the market price. The stock of the quasi-fixed capital K is specified by x_K .

²² Equation (5) represents the final specification of the shadow price equation, which is estimated in the system of seemingly unrelated regressions to quantify the measure of climate policy stringency. D is a country-, sector and time-specific dummy variable and α_E as well as λ_E are the respective regression coefficients. Given the limited number of degrees of freedom, the time-specific effect is structured in five equivalent three-year time periods.

In order to estimate the coefficients α of the cost function, factor demand functions of the two variable inputs are computed with the help of Shephard's lemma. Moreover, each factor demand function is divided by the output to make different sector sizes comparable:

$$(7) \quad \frac{x_{L,ict}}{y_{ict}} = \frac{1}{y_{ict}} \frac{\partial C_{ict}}{\partial p_{L,ict}} = 0.5\alpha_{LL} \frac{1}{p_{L,ict}^{0.5}} + 0.5\alpha_{LE} \frac{Z_{E,ict}^{0.5}}{p_{L,ict}^{0.5}} + \alpha_{LK} \frac{x_{K,ict}^{0.5}}{y_{ict}^{0.5}} + \alpha_{KK} \frac{x_K^{0.5}}{y_{ict}}$$

and

$$(8) \quad \frac{x_{E,ict}}{y_{ict}} = \frac{1}{y_{ict}} \frac{\partial C_{ict}}{\partial Z_{E,ict}} = 0.5\alpha_{EE} \frac{1}{Z_{E,ict}^{0.5}} + 0.5\alpha_{LE} \frac{p_{L,ict}^{0.5}}{Z_{E,ict}^{0.5}} + \alpha_{EK} \frac{x_{K,ict}^{0.5}}{y_{ict}^{0.5}} + \alpha_{KK} \frac{x_K^{0.5}}{y_{ict}}$$

The system of the three equations (5), (7), and (8) is estimated using seemingly unrelated regressions, a method introduced by Zellner (1962) that facilitates the estimation of common coefficients across different equations. After obtaining the estimated coefficients, the sector-specific wedges and the shadow prices can be quantified. In this paper, the wedges λ_E will be used as the measure of climate policy stringency, because the wedges isolate the differences between the specific stringencies and the sectoral market average stringency and, hence, are not potentially biased by overall changes in the market average stringency.

As introduced in section 2.1 measures of environmental policy are likely to be endogenous. To rule this out an endogeneity test from Wooldridge (2010, 2013) is applied, which does not provide indication for the presence of endogeneity.²³ Therefore, no additional instrumental variable for the estimated wedges λ_E is determined.

4.3 Instrument for trade openness

The second explanatory variable that requires careful consideration is trade openness. Following earlier literature the trade openness of country C_1 with country C_2 is defined as the sum of bilateral export and import trade flows as the share of output y (Frankel and Romer 1999; Frankel and Rose 2002):

$$(9) \quad TO_{C_1C_2,t} = \frac{EXP_{C_1C_2,t} + IMP_{C_1C_2,t}}{y_{C_1,t}} \text{ with } C_1 \neq C_2$$

As can be noted from this definition, problems of endogeneity may arise between trade openness and net imports per output, the response variable in the main model (4). A simple regression of trade openness on relative net imports would imply the assumption that countries that are more engaged in trade are, therefore, likely to have comparatively higher net imports or net exports. Besides trade imbalances paired with high trade intensities, there is no obvious reason why such a direct relationship would be expected. Rather other (macroeconomic) reasons different from pure trade openness are expected to determine whether a country is an exporter or an importer. At the same time, the level of trade openness may be influenced by the trade pattern. For example, driven by trade imbalances,

²³ Unlike the Hausman test and the Durbin-Wu-Hausman test, this test does not require the estimation of an additional measure that can be used as an instrumental variable. The test rather regresses all exogenous variables on the potentially endogenous one, saves the residuals, and adds them to equation (4) to test if the residuals are statistically significant.

by a fear of dirty or unsecure goods imports from abroad, and to protect infant industries from import competition policy makers may want to adjust tariff rates. A Hausman test for endogeneity supports this suspicion.²⁴ In order to address the endogeneity problem an instrument for trade openness is estimated with the help of a gravity model of international trade using geography and population size characteristics.

First introduced by Tinbergen (1962) and Pöyhönen (1963) the gravity model of international trade has become an important empirical tool owing to its convenience and good fit with the data. Yet, the general theoretical foundation of the gravity model has been under discussion (Anderson and van Wincoop 2003). Deardorff (1998) concludes that an empirical model that can be derived from conflicting theories is not the right tool to discriminate between them. Nevertheless, in search of an instrument, which is both exogenous and highly correlated with trade, Frankel and Romer (1999) introduce a gravity-based instrument using a two-stage procedure. In the first step, the bilateral trade equation is estimated on the basis of a gravity model with exogenous explanatory variables. For each country the fitted bilateral trade values with the trading partners are then aggregated to determine the country's overall trade openness. In the second step, the overall fitted values are used as an instrument in the estimation of the main equation. In several other articles this concept provides a good instrument for trade openness (Frankel and Rose 2002; Irwin and Terviö 2002; Löschel et al. 2013) and will, hence, be used to account for the endogeneity problem. The following specification of the gravity equation is estimated in the first stage:

$$(10) \quad \ln TO_{C_1C_2,t} = \gamma_0 + \gamma_1 \ln Dist_{C_1C_2} + \gamma_2 \ln Pop_{C_1,t} + \gamma_3 \ln Pop_{C_2,t} + \gamma_4 \ln Area_{C_1} \\ + \gamma_5 \ln Area_{C_2} + \gamma_6 (LL_{C_1} + LL_{C_2}) + \gamma_7 CB_{C_1C_2} + \gamma_8 CB_{C_1C_2} \ln Dist_{C_1C_2} \\ + \gamma_9 CB_{C_1C_2} \ln Pop_{C_1,t} + \gamma_{10} CB_{C_1C_2} \ln Pop_{C_2,t} + \gamma_{11} CB_{C_1C_2} \ln Area_{C_1} \\ + \gamma_{12} CB_{C_1C_2} \ln Area_{C_2} + \gamma_{13} CB_{C_1C_2} (LL_{C_1} + LL_{C_2}) + \varepsilon_{C_1C_2,t}$$

Besides the geographic distance between the trading partners' capitals *Dist*, two measures of size, namely the countries' population size *Pop* and area *Area*, are included in the model. As landlockedness *LL* and common borders *CB* may affect trade flows, they are included as dummy variables. In addition, the common border dummy is interacted with all other explanatory variables to describe differences in trade with neighboring countries more precisely. In the style of previous research, equation (10) is estimated using least squares (Löschel et al. 2013).²⁵ The results are depicted in *table 2* and are generally as expected. The distance between the trading partners has, ceteris paribus, a strong negative impact on the size of bilateral trade flows. While larger partner countries *C*₂ in terms of population and area are beneficial for trade, trade flows are decreasing with growing population sizes of the

²⁴ The Hausman test analyzes whether significant differences between the OLS estimates and the 2SLS estimates exist. For this procedure the instrumental variable, which is subsequently described, is used in the 2SLS estimation.

²⁵ It should be noted that during the time period under consideration from 1995 to 2009 the trade flows between the 40 analyzed countries changed rapidly. This can be, among other things, attributed to the trade opening after the fall of the Iron Curtain, to globalization and outsourcing activities, and to the world financial crisis starting in 2008. At the same time, the geography variables of individual countries were not subject to change and only the population sizes altered. Due to this missing variation a (random effects) panel estimator can account for differences in trade flows between countries, but not for the time-specific effects within countries. Consequently, following Löschel et al. (2013) the gravity model is estimated for each year individually. In order to visualize the results the pooled OLS estimates, which show similar coefficients, are displayed. The individual estimates for each year are available upon request.

respective country C_1 under consideration. Moreover, landlocked countries tend to trade less and in total a common border has a positive effect on trade openness.

	$\ln(TO_{C_1C_2} / 1000)$				
	Coefficient		(rob. SE)		
$\ln Dist_{C_1C_2}$	-0.953	***	(0.012)	Number of obs.	23,400
$\ln Pop_{C_1}$	-0.209	***	(0.010)	F(13, 23,386)	1,629
$\ln Pop_{C_2}$	0.559	***	(0.010)	Prob. > F	0.000
$\ln Area_{C_1}$	0.036	***	(0.008)	R-squared	0.464
$\ln Area_{C_2}$	0.043	***	(0.007)	Root MSE	1.500
$(LL_{C_1} + LL_{C_2})$	-0.387	***	(0.021)		
$CB_{C_1C_2}$	-0.725	*	(0.404)		
$CB_{C_1C_2} \ln Dist_{C_1C_2}$	-0.033		(0.092)		
$CB_{C_1C_2} \ln Pop_{C_1}$	-0.211	***	(0.043)		
$CB_{C_1C_2} \ln Pop_{C_2}$	0.000		(0.043)		
$CB_{C_1C_2} \ln Area_{C_1}$	0.125	***	(0.045)		
$CB_{C_1C_2} \ln Area_{C_2}$	0.024		(0.043)		
$CB_{C_1C_2} (LL_{C_1} + LL_{C_2})$	0.221	***	(0.052)		
Constant	6.679	***	(0.119)		

Table 2: Regression results of the gravity model (Significance codes: * p< .10, ** p<.05, *** p<.01)

To determine a country's overall trade openness, which is the respective regressor used in the pollution haven model (4), the fitted values from the gravity equation across all bilateral trading partners are aggregated:

$$(11) \quad T\hat{O}_{C_1,t} = \frac{\sum_{C_1 \neq C_2} (EXP_{C_1C_2,t} + IMP_{C_1C_2,t}) + EXP_{C_1ROW,t} + IMP_{C_1ROW,t}}{\sum_{C_1 \neq C_2} (EXP_{C_1C_2,t} + IMP_{C_1C_2,t})} \sum_{C_1 \neq C_2} e^{\hat{\gamma}' X_{C_1C_2,t}}$$

Here, X is the vector of the explanatory variables in equation (10) and $\hat{\gamma}'$ are the respective estimated coefficients. The calculation of the constructed trade openness is limited to bilateral trade between the 40 countries in the WIOD. For this reason, an additional adjustment factor is included for trade with countries of the rest of the world ROW .²⁶ The determined country-specific trade openness is used as an instrument in the estimation of the second-stage regression, i.e. the pollution haven equation (4).

5 Results and discussion

The results of the two-stage least squares estimation of equation (4) are shown in *table 3* for the different measures of pollution intensity.²⁷ The presented regression results for both the pollution haven effect and the hypothesis for dirty sectors are robust regarding alternative

²⁶ Unlike the original work of Frankel and Romer (1999), who focus only on U.S. trade flows, this paper considers bilateral trade between the 40 countries in the WIOD. The adjustment factor makes the measure comparable for the various countries as different trade shares are explained by the bilateral trade data. On average 87 percent of the trade flows for the 28 countries analyzed in the pollution haven model are explained by the bilateral trade flows in the WIOD. The adjustment factor assumes that a country C_1 has on average the same trade openness for trade with countries in the rest of the world as for trade with the WIOD countries.

²⁷ Alternative specifications using carbon dioxide emission intensity as the measure of pollution intensity can be found in *tables 8* and *9* in appendix 3. Further regression estimates are available upon request.

specifications. In order to correct for potential heteroscedasticity robust standard errors are determined.

Dirty sectors based on average sector:	<i>Net Imports/Output</i>					
	CO₂ emission intensity		Emission relevant energy intensity		Gross energy intensity	
	Coefficient	(rob. SE)	Coefficient	(rob. SE)	Coefficient	(rob. SE)
$\lambda_{E_{t-1}}$	-16.00	(10.56)	-15.48	(10.64)	0.18	(9.13)
TO	15.19	(10.87)	15.10	(10.90)	14.48	(10.90)
$\bar{\lambda}_E \cdot TO$	21.56 ***	(2.30)	22.07 ***	(2.34)	17.74 ***	(2.05)
$\lambda_{E_{t-1}} \cdot x_E / y$	0.05 **	(0.02)	1.13 **	(0.47)	-0.50	(0.55)
$\bar{\lambda}_E \cdot TO \cdot x_E / y$	-0.02	(0.01)	-0.48 *	(0.26)	0.12	(0.22)
$CapComp / y$	-357.39 ***	(23.24)	-357.12 ***	(23.16)	-346.74 ***	(22.78)
$HSLabor / y$	-437.53 ***	(29.12)	-435.25 ***	(28.91)	-425.27 ***	(28.64)
$MSLabor / y$	-213.25 ***	(32.63)	-212.17 ***	(32.42)	-201.64 ***	(32.10)
$LSLabor / y$	-56.12	(43.80)	-57.91	(43.88)	-46.22	(43.38)

Table 3: Regression results of the pollution haven model (Significance codes: * p< .10, ** p<.05, *** p<.01; the regressions are estimated with sector, country, and time fixed effects)

With regards to the impact of the lagged climate policy stringency on net imports the regression estimates exhibit several findings. The general impact of the lagged regulation variable is not significant when both the pollution haven effect and the hypothesis are estimated simultaneously. However, the coefficient becomes positive and highly significant in a specification that solely tests for the existence of a pollution haven effect. This suggests that the stringency of climate regulation has indeed to some extent a general impact on the trade flows of all sectors including cleaner sectors. Interestingly, the coefficient of the interaction term with pollution intensity is positive and significant on the five percent level for carbon dioxide emission intensive and emission relevant energy intensive sectors, but not significant for gross energy intensive sectors. Thus, a rise in climate policy stringency partly results in larger increases in the net imports for pollution intensive sectors. While this indicates that a stronger pollution haven effect for dirty sectors exists, the discrete impact of climate policy on the competitiveness of dirty domestic sectors seems to be limited and does not comprise mere gross energy intensive sectors. Climate policy appears to influence in particular the economic activity of sectors with high global pollution emissions. The findings are confirmed when the wedges are directly used as the measure of regulatory stringency instead of the lagged wedges.

Different results are obtained concerning the joint impact of trade liberalization and climate policy stringency. The coefficient of the general effect is estimated to be positive and significant on the one percent level. In other words, increases in trade openness have in general a larger positive impact on the net imports for sectors with a comparatively stringent average climate policy regulation. Given that trade barriers are sufficiently low, strictly regulated sectors seem to be able to react on their altered terms of trade and change their patterns of trade by importing relatively more of the dirty good. In contrast to that, the respective coefficients of the pollution intensity interaction term are estimated to be either insignificant or negative and marginally significant. Hence, an increase in trade liberalization is associated with the same or smaller net imports of dirty sectors facing stringent regulation compared to the general impact. This is contrary to the predictions of the stronger pollution haven hypothesis and confirms the findings of earlier research presented in section 2.2. It suggests that the costs associated with climate regulation are not sufficiently higher for pollution intensive sectors compared to the ones of the average sector to bring about a

distinct incentive for plant relocations of the dirty goods production. Climate policy seems to be only one factor among others to affect trade flows. The results are robust with respect to all three specifications for dirty sectors and to changes in the specification. Using wedges or lagged wedges instead of time invariant average wedges provides support for a general impact but no support for a stronger influence on pollution intensive sectors.

As expected the general impact of the country-specific trade openness on the net imports is insignificant after taking the endogeneity into account and including country-specific fixed effects. This is in accordance with theory that other factors determine the pattern of trade.²⁸

On the contrary, the coefficient estimates of the Heckscher-Ohlin variables are with the exception of the low-skilled labor intensity all highly significant and negative, which seems to be at least for the high-skilled labor intensity unexpected. Nevertheless, the counterintuitive sign can be attributed to three reasons. First, the majority of trade takes place between developed countries and the dataset includes only OECD countries. Second, intra-industry trade has become more important and the same sectors tend to have analogous factor intensities (Althammer and Mutz 2010). Third, this paper includes country-specific fixed effects as additional controls. When the respective variables are left out of the specification the signs become more intuitive. A positive but insignificant coefficient is then estimated for the high-skilled labor intensity and negative as well as significant coefficients are determined for the remaining factor intensities. Nonetheless, when the fixed effects are included the coefficient estimates are robust to changes in the specification. Thus, while the comparative advantage in factors of production may not be prevailing in this specification, the Heckscher-Ohlin variables are still kept to control for heterogeneity across sectors.

As a last step, the quality of the trade openness instrument, which is introduced in section 4.3, needs to be assessed. This includes the analysis of both the strength of the instrumental variable and the validity of the included adjustment factor. On the one hand, following Stock et al. (2002) the criterion that the F-statistic of the first-stage regression needs to be larger than ten is fulfilled. In other words, the results of the two-stage least squares estimator are reliable and the endogeneity problem can be addressed with the help of the gravity-based instrument.²⁹ On the other hand, when the adjustment factor for trade with the rest of the world is not applied to the pollution haven model (4), a negative trade openness coefficient can be observed. This would imply that, among other things, pure trade openness determines the pattern of trade and is in contradiction with economic reasoning. As this indicates that the omission of trade with the rest of the world may result in biased estimates, the use of the adjustment factor is preferred. All in all, the implemented trade openness instrumental variable suffices econometrical standards.

²⁸ When dropping the country-specific dummy variables and, hence, relieving the condition that the controls need to account for heterogeneity across countries, the trade openness coefficient becomes highly significant and negative. The coefficient estimate indicates that for the set of countries, nations which experienced larger increases in trade openness tend to be exporters.

²⁹ Despite of this, the provided evidence for the distinct dirty sectors' pollution havens remains unchanged if equation (4) is determined using fixed effects estimation instead of the two-stage least squares estimator. However, the magnitude of the estimated effects becomes smaller.

6 Conclusion

Given the ambiguous empirical results of previous research, this paper tests whether support for a climate policy induced pollution haven effect and the pollution haven hypothesis can be found. Thereby, the paper includes several methodological novelties. By arguing that trade flows of dirty goods to less polluting sectors may also be influenced by changes in policy stringency, trade information on primary, secondary, and tertiary sectors are included in the analysis. In order to clearly differentiate between dirty sectors and sectors with high pollution abatement costs, separate measures for pollution intensity and policy stringency are implemented. For the latter a consistent, internationally comparable, sector-specific measure of climate policy stringency is estimated based on a shadow price approach. Potential problems of endogeneity between a country's trade openness and the respective trade flows are addressed through the inclusion of an instrumental variable.

The result exhibit international empirical evidence for a stronger pollution haven effect regarding carbon dioxide intensive and emission relevant energy intensive sectors. However, the impact of climate policy regulation on polluting sectors seems to be rather limited as a distinct pollution haven effect for gross energy intensive sectors cannot be found. In addition, no support is revealed for the hypothesis that trade liberalization causes a special shift of dirty sectors to countries with weak climate policy stringency. Unlike the majority of previous research the results are based on a broad international dataset including former transforming nations from Eastern Europe and newly industrialized countries like Mexico and Turkey for the time period from 1995 to 2009. Hence, among other things, impacts of the implementation of the Kyoto protocol in a multiple country setting are taken into account.

Future research may refine the analysis in three ways. First, despite the comparatively large coverage of the dataset, the number of countries, that are not highly developed, can be further increased. Following the argumentation of Ederington et al. (2005) the inclusion of developing countries and non-OCED countries allows analyzing the trade flows between more countries at different stages of development and, hence, helps to verify the impact of climate policy regulation. Second, while the existing evidence implies that other factors are more important than climate policy regulation to determine the pattern of trade, an adapted specification of the trade openness variable may further clarify the validity of the pollution haven hypothesis. For this reason, the use of an instrumental variable for sector-specific trade openness is suggested. This paper shows that it is relevant to take simultaneity of trade openness into account. Concurrently, the level of trade liberalization may vary across sectors within one country. Higher trade barriers may be implemented to protect specific industries from international competition, whereas this may not be the case for other sectors that are highly competitive or produce non-tradable goods. Last, the focus on sector-specific bilateral trade and intra-national trade can potentially provide more precise estimates than the analysis of aggregated sectoral trade flows. With regards to intermediate goods pollution intense sectors as well as less polluting sectors use both dirty goods and other goods for the further processing. While aggregated trade flows reflect this characteristic, the use of aggregated trade flows to only analyze the impact of climate policy stringency on the trade flows of dirty goods may result in downward biased estimates. Therefore, a sector-specific analysis of the origin and destination of dirty goods is expected to further clarify the extent of pollution havens.

Appendix 1: Overview of final variables

Abbreviation	Final variable	Unit of measurement
Pollution haven model		
NI	Net imports	Millions of 2005 U.S. dollars
y	Gross output	Billions of 2005 U.S. dollars
λ_E	Wedge between shadow price of emission relevant energy and market average	Thousands of 2005 U.S. dollars per ton of oil equivalent
TO	Trade openness	2005 U.S. dollars per thousands of 2005 U.S. dollars
x_E	Carbon dioxide emissions	Kilotons
x_E	Emission relevant energy use	Millions of tons of oil equivalent
x_E	Gross energy use	Millions of tons of oil equivalent
$CapComp$	Capital compensation	Billions of 2005 U.S. dollars
$HSComp$	High-skilled labor compensation	Billions of 2005 U.S. dollars
$MSComp$	Medium-skilled labor compensation	Billions of 2005 U.S. dollars
$LSComp$	Low-skilled labor compensation	Billions of 2005 U.S. dollars
Shadow price estimation		
y	Gross output	Billions of 2005 U.S. dollars
Z_E	Shadow price of emission relevant energy	Thousands of 2005 U.S. dollars per ton of oil equivalent
p_E	Sector-specific average market energy price	Thousands of 2005 U.S. dollars per ton of oil equivalent
p_L	Average wage	Thousands of 2005 U.S. dollars
x_K	Capital stock	Billions of 2005 U.S. dollars
x_L	Employment	Millions of man years worked
x_E	Emission relevant energy use	Millions of tons of oil equivalent
Gravity model to estimate trade openness instrument		
TO	Trade openness	2005 U.S. dollars per thousands of 2005 U.S. dollars
$Dist$	Geographic distance between capitals	Kilometers
Pop	Size of population	Millions of people
$Area$	Total area	Square kilometers

Table 6: Used variables and their units of measurement (Dummy variables are not included in the overview)

Appendix 2: Sector overview

ISIC Rev. 3.1	Sector
AtB (01t05)	Agriculture, hunting, forestry, and fishing
C (10t14)	Mining and quarrying
15t16	Food, beverages, and tobacco
17t18	Textiles and textile products
19	Leather, leather and footwear
20	Wood and products of wood and cork
21t22	Pulp, paper, printing, and publishing
23	Coke, refined petroleum, and nuclear fuel
24	Chemicals and chemical products
25	Rubber and plastics
26	Other non-metallic mineral
27t28	Basic metals and fabricated metal
29	Machinery, nec
30t33	Electrical and optical equipment
34t35	Transport equipment
36t37	Manufacturing, nec; recycling
E (40t41)	Electricity, gas and water supply
F (45)	Construction
50	Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel
51	Wholesale trade and commission trade, except for motor vehicles and motorcycles
52	Retail trade, except for motor vehicles and motorcycles; repair of household goods
H (55)	Hotels and restaurants
60	Inland transport
61	Water transport
63	Other supporting and auxiliary transport activities; activities of travel agencies
64	Post and telecommunications
J (65t67)	Financial intermediation
70	Real estate activities
71t74	Renting of M&Eq and other business activities
L (75)	Public admin and defence; compulsory social security
M (80)	Education
N (85)	Health and social work
O (90t93)	Other community, social, and personal services

Table 7: Included sectors in the main model and the respective division-level ISIC Rev. 3.1

Appendix 3: Supplementary regression results of the pollution haven model using carbon dioxide emission intensity as the measure of pollution intensity

Change in specification	<i>Net Imports/Output</i>					
	Only pollution haven effect analyzed		Use of wedges instead of lagged wedges		Use of lagged wedges instead of av. wedges	
Original specification	Coefficient	(rob. SE)	Coefficient	(rob. SE)	Coefficient	(rob. SE)
$\lambda_{E,t-1}$	73.15 ***	(5.71)	-12.39	(9.69)	15.40	(17.76)
TO	7.75	(10.63)	14.47	(9.43)	14.79	(11.76)
$\bar{\lambda}_E \cdot TO$			20.85 ***	(2.17)	13.92 ***	(4.28)
$\lambda_{E,t-1} \cdot x_E / y$	0.02 *	(0.01)	0.06 ***	(0.02)	0.09 ***	(0.03)
$\bar{\lambda}_E \cdot TO \cdot x_E / y$			-0.02 *	(0.01)	-0.03 **	(0.01)
$CapComp / y$	-362.01 ***	(22.32)	-354.52 ***	(21.93)	-369.09 ***	(23.66)
$HSLabor / y$	-459.28 ***	(28.40)	-435.71 ***	(27.68)	-457.73 ***	(30.52)
$MSLabor / y$	-213.38 ***	(31.15)	-213.42 ***	(30.92)	-229.63 ***	(33.17)
$LSLabor / y$	-85.29 **	(42.46)	-48.91	(41.43)	-83.69 *	(44.97)

Table 8: Regression results of alternative specifications for the pollution haven model 1 (Significance codes: * p<.10, ** p<.05, *** p<.01; the regressions are estimated with sector, country, and time fixed effects)

Change in specification	<i>Net Imports/Output</i>					
	Fixed effects instead of 2SLS		No inclusion of the rest of the world adjustment factor for the variable TO		No inclusion of country fixed effects	
Original specification	Coefficient	(rob. SE)	Coefficient	(rob. SE)	Coefficient	(rob. SE)
$\lambda_{E,t-1}$	52.37 ***	(6.60)	-0.53	(9.08)	50.10 ***	(11.58)
TO	0.22	(1.14)	-25.63 **	(11.08)	-18.22 ***	(1.17)
$\bar{\lambda}_E \cdot TO$	4.81 ***	(0.98)	19.03 ***	(1.85)	-12.31 ***	(2.77)
$\lambda_{E,t-1} \cdot x_E / y$	0.02 *	(0.01)	0.05 ***	(0.02)	0.05 **	(0.03)
$\bar{\lambda}_E \cdot TO \cdot x_E / y$	0.00	(0.00)	-0.01 *	(0.01)	-0.04 **	(0.02)
$CapComp / y$	-362.37 ***	(22.71)	-371.51 ***	(24.02)	-452.23 ***	(33.80)
$HSLabor / y$	-453.13 ***	(28.56)	-445.90 ***	(29.86)	30.87	(46.82)
$MSLabor / y$	-214.14 ***	(31.22)	-225.24 ***	(32.33)	-581.33 ***	(46.00)
$LSLabor / y$	-91.17 **	(40.43)	-124.02 ***	(44.44)	-706.67 ***	(66.39)

Table 9: Regression results of alternative specifications for the pollution haven model 2 (Significance codes: * p<.10, ** p<.05, *** p<.01; the regressions are estimated with sector, time, and partly country fixed effects)

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