Resource and Energy Economics 71 (2023) 101336

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

Home country bias in international emissions trading: Evidence from the EU ETS

Beat Hintermann [a,*], Markus Ludwig [b]

[a] University of Basel, Faculty of Business and Economics, Peter Merian-Weg 6, 4002 Basel, Switzerland
[b] Technical University of Braunschweig, Institute of Economics, Spielmannstrasse 9, 38106 Braunschweig, Germany

ARTICLE INFO

Article history:
Received 6 October 2021
Received in revised form 10 August 2022
Accepted 2 October 2022
Available online 4 October 2022

JEL classification:
F14
F18
Q52
Q54
Q58

Keywords:
Emission permit market
EU ETS
Transactions costs
Gravity model
Home bias

ABSTRACT

We examine the pattern of allowance trades in the European Union Emissions Trading System (EU ETS) using highly disaggregated trading data and identify a significant and robust home market bias. Our results point to informational transactions costs that increase when trading across national borders. The existing trade pattern in goods and services explains two thirds of the home bias, with the remainder due to other causes. Our finding suggests that firms make use of existing trade networks to overcome search costs in bilateral allowance trade. Since the home bias differs across firms, it follows that marginal abatement costs are not equalized across market participants of the EU ETS.

1. Introduction

The Paris Agreement is based on "nationally determined contributions" towards the global reduction of greenhouse gas (GHG) emissions. Many countries decided to introduce (or expand) a domestic cap-and-trade market for GHG emissions. Because the costs of emissions reduction vary significantly across countries, national regulators hope to link domestic systems into multinational markets (Green et al., 2014). The expected gains from trade stem from the equalization of marginal abatement costs across all firms in the linked markets. The success in achieving the emissions target at least cost, however, depends on the efficient functioning of the multinational market.

In this paper, we investigate allowance trade flows within the European Union Emission Trading System (EU ETS). The EU ETS is the flagship of the EU's climate policy, and the only truly multinational permit market to date. Our analysis is based on the universe of allowance transactions during the years 2005–2013 and uses gravity framework developed in the context of in-

* Corresponding author.
E-mail addresses: b.hintermann@unibas.ch (B. Hintermann), markus.ludwig@tu-braunschweig.de (M. Ludwig).

https://doi.org/10.1016/j.reseneeco.2022.101336

ternational trade. We find robust evidence for a home (country) bias in the sense that market participants are significantly more likely to trade within than across national borders, ceteris paribus.[1] The home bias is robust to using alternative sub-samples, and it is manifested along both margins of trade: Firms are more likely to purchase allowances from domestic trade partners than international ones, and conditional on a trade taking place, the volume is greater for domestic purchases. Because emissions allowances are perfectly homogenous goods transmitted electronically at no transportation cost, the existence of a home bias points to the presence of transactions costs that accrue when trading emissions allowances across national borders.

Our paper contributes to the literature in two ways. The first pertains to the empirical literature on permit markets. Previous studies show that transactions costs can keep certificate markets from functioning effectively.[2] Transactions costs have been shown to be important in the EU ETS, mostly in the context of monitoring, reporting and verifying emissions (Jaraitė et al., 2010; Heindl, 2012; Sandoff and Schaad, 2009; Heindl and Lutz, 2012), and they can potentially explain the puzzle of why some firms completely abstained from the market during the first years (Jaraitė et al., 2010; Zaklan, 2013; Hintermann, 2017). Zaklan (2013) finds that larger firms are more likely to buy (but not to sell) allowances, and that firms' ownership structure and industrial classification affect the propensity to trade. However, neither productivity nor profitability appear to play a role. Jaraitė-Kažukauskė and Kažukauskas (2014) report that firms owning several installations covered by the EU ETS, as well as firms that have previously traded, are more likely to participate in trade (and trade larger amounts), which they interpret as evidence for the relevance of transactions costs in the market. Our analysis builds on these two papers and extends them in several dimension: (i) we include all market participants (i.e., not only firms covered by the EU ETS), (ii) we use data from 2005 through 2013 (thus covering the full first two phases plus the beginning of the third phase), and (iii) we focus on the international component of allowance trade by creating a trade matrix and using a gravity model. To our knowledge, the only other paper that explicitly examines cross-border allowance trade is by Ellerman and Denny (2009), who present evidence for the existence of international allowance trade on a country level but do not examine the presence of a home bias.

We identify substantial heterogeneities in the magnitude of the home bias across firms of different size and location, which implies that the total allowance costs (i.e., the sum of EUA price and transactions costs) are not equalized. Since cost-minimizing firms set their marginal abatement costs equal to the total costs of allowances, the presence of heterogeneous transactions costs indicates that marginal abatement costs are not equalized across polluters in the EU ETS (Stavins, 1995; Montero, 1997; Hahn and Stavins, 2011).[3]

Our second contribution is to the gravity literature in international trade, on which we build methodologically. A number of papers have documented a home bias in the trade of goods and commodities (McCallum, 1995; Evans, 2003; Anderson and Wincoop, 2003; Wolf, 2000), which has been described as one of the major puzzles in international macroeconomics (Obstfeld and Rogoff, 2001). The literature has proposed various potential channels to explain this phenomenon, such as differences in the elasticity of substitution in production, preferences about the "nationality" of a product, explicit trade barriers arising at national borders or the exercise of market power.[4] The characteristics of the EU ETS exclude some of the these possible sources of home bias. First, because allowances are perfectly homogenous, the home bias cannot be due to a difference in consumer preferences across borders. Second, allowances exist only electronically and are therefore traded without transportation costs. And third, since we observe all allowance transactions, we know that the trade connections with zero activity in fact represent an absence of trade as opposed to missing data, a problem that routinely plagues the analysis of trade in physical goods. Using the example of the EU ETS, we thus contribute to the literature by providing empirical evidence for a home bias in international trade that is unrelated to transport costs, preferences or missing data.

We find that an important part of the informational trading costs are sunk, which is consistent with foreign market entry costs related to cross-border information frictions (Chaney, 2014; Rauch, 2001; Melitz, 2003). As would be expected in this case, we observe that the magnitude of the home bias decreases over time as new trade connections are established. However, it does not completely dissipate and persists in the last year in our sample. Furthermore, about three quarters of the home bias in the trade for emission allowances can be explained by the trade pattern in goods and services, for which a well-documented home bias exists (see, e.g., Wolf, 2000; McCallum, 1995). This indicates that firms make use of existing trade networks to overcome information asymmetries and/or search costs in bilateral allowance trade. This result is consistent with similar findings by Aviat and Coeurdacier (2007), who demonstrate a home bias in financial asset holding that is closely related to the bilateral trade pattern in goods.[5] Our results thus imply that international trade frictions exist even in the absence of transportation costs and,

[1] Throughout this paper, we mean home country bias when we refer to home bias, using the convention from the literature on international trade. Naturally, one could define "home" to mean other territorial units such as regions or metropolitan areas.

[2] This literature includes Hahn and Hester (1989); Kerr and David (1998); Gangadharan (2000); for a review, see Krutilla et al. (2011).

[3] Given heterogeneous marginal transactions costs, mtc_i, across polluters i, we have $mac_i = p - mtc_i$, where p is the permit price and mac_i refer to marginal abatement costs. Note that even if transactions costs were homogenous and marginal abatement costs thus equalized, they still lead to a price wedge between marginal abatement costs and the allowance price. This increases the overall social cost of achieving the emissions cap, because allowance prices are passed on to consumers, e.g., in the form of higher electricity prices (Fabra and Reguant, 2014; Fell et al., 2015; Hintermann, 2016).

[4] Evans (2003) focuses on differences in production elasticites, Brülhart and Trionfetti (2009) and Coşar et al. (2018) on differences in preferences across countries, and Blum and Goldfarb (2006), Atkin (2013) and Auer (2017) on taste differences across regions. Anderson and Wincoop (2004) and Obstfeld and Rogoff (2001) explain the home bias with explicit trade barriers. Roux et al. (2016) examine the effect of market power on the home bias. Blum and Goldfarb (2006) document a negative effect of geographical distance on bilateral trade volumes of differentiated digital (online) goods that are traded without transportation costs, a feature shared by allowance trade.

[5] Rauch (2001) and Combes et al. (2005) discuss the importance of business networks in domestic and international trade. On average, firms can rely on a less extensive international trade network, relative to their domestic trade network, which decreases the probability of finding an international trade partner in bilateral allowance trade.

what is particularly striking, among countries that share a common market for goods and services, such as the members of the EU.

In the next section, we present the data and the econometric model. In section 3, we present our results, investigate potential mechanisms and carry out a series of robustness tests. Section 5 concludes.

2. Data and empirical strategy

We start by providing some background information about allowance trade in the EU ETS before describing the data and our empirical strategy. Our sample period covers the years 2005–2013.

2.1. Allowance trade in the EU ETS

The EU ETS is a cap-and-trade system in operation since 2005 and covers energy-intensive installations from all EU members and from additional countries that have linked into the system over time. Installations covered by the EU ETS have to surrender one EU allowance, or EUA, for each metric ton of CO_2 that they emitted during the previous calendar year. The total number of allowances that are distributed each year, either for free or in auctions, constitutes the annual CO_2 emissions cap in the EU ETS. For a review of the EU ETS and the related literature, the interested reader is referred to the recent symposium by Ellerman et al. (2016), Hintermann et al. (2016) and Martin et al. (2016).

Allowances are issued electronically and held in different types of accounts owned by *account holders*, who may hold several accounts. The accounts are located in national registries established by each country participating in the EU ETS. The national registries are joined in the EU Transactions Log (EUTL), which is centrally managed by the EU.[6] Within this system, transfers of allowances are only possible through accounts. Furthermore, transfers of permits across accounts are not subject to explicit transactions costs.

All installations covered by the EU ETS are assigned what is called an operator holding account (OHA). Firms with multiple covered installations own an OHA for each. The national governments use government accounts to distribute allowances into firms' OHAs. Each April, firms transfer the number of allowances required to cover their emissions during the previous calendar year from their OHAs into a different government account. These allowances are then canceled.

In addition to government accounts and OHAs, allowances can be held in a personal holding account (PHA). Such an account can be set up by a covered firm to collect allowances from different OHAs that it owns, and thus serve as a centralized trading account. Furthermore, any firm or person that wishes to trade allowances can open a PHA in one of the national registries, and some financial institutions (which themselves are not covered by the ETS) have engaged in extensive allowance trading via PHAs.

Allowance trade can take place bilaterally between two account holders or on organized exchanges. Currently, the exchange that dominates allowance trade is the European Energy Exchange (EEX).[7] In the beginning of the EU ETS and during most of our sample period, the exchange with the largest allowance trade volume was BlueNext. This exchange was located in France but closed in December of 2012. The majority of countries that are part of the EU ETS do not have a formal exchange within their borders.

The (mostly fixed) fees and admission procedures (which, at EEX, include an online trader exam) make exchange trades attractive only for firms that trade significant volumes of allowances per year. Firms that trade relatively small amounts can therefore be expected to use intermediaries (e.g., brokers) in an over-the-counter trade. Unfortunately, our data does not include the information whether a trade took place bilaterally, over the counter or on an exchange.

2.2. Data and aggregation

We limit our analysis to transactions between firms and thus exclude transactions related to the allocation and surrender of allowances. Our data comprises the universe of transactions between OHAs and PHAs between 2005 and 2013.[8] Besides the transaction amount, the data includes the date of the transaction, the account identifiers of the buying and selling accounts and the names and addresses of the involved account holders. Transactions data are published with a delay of three years. Annual updates occur each June and include transactions through April the calendar year three years prior to the update. For example, in June 2017, transactions data became available through April 2014. Since we aggregate to the yearly level, we use data through 2013, which include a total of 436,650 individual transactions between OHAs and PHAs.

Firms owning several plants can concentrate allowances in a centralized PHA and use this account to buy and sell allowances on the market in order to minimize transactions costs. In order to surrender the allowances to cover their emissions for the previous calendar year, the firm-level PHA transfers the appropriate number of allowances to each OHA before the submission

[6] The EUTL replaced the Community Independent Transactions Log (CITL), which was a web interface that joined the independently managed country registries. The data previously contained in CITL data has been transferred to EUTL.

[7] Allowances can currently also be traded on Nasdaq Commodities, Climex and NYMEX, but the trading volumes on these exchanges is negligible relative to that on the EEX. Until 2011, allowances could also be traded on the Austrian Energy Exchange.

[8] The data is freely available at http://ec.europa.eu/environment/ets/, with a delay of three years.

date. Defining trades between accounts belonging to the same firm as regular allowance trade would artificially inflate the home bias if the different accounts are located within the same country (which would be expected). For our empirical analysis, we therefore aggregate the data from the account to the firm level, thus making the firm the unit of analysis. We do this by linking the EUTL accounts to Bureau van Dijk's Orbis database, using a similar approach as Zaklan (2013) and Jaraitė-Kažukauskė and Kažukauskas (2014).[9] We accomplish the merging between the EUTL and Orbis data based on firm names and addresses (i.e., countries and sometimes zip codes). This removes 41,992 transactions between accounts belonging to the same firm. We retain accounts for which we find no entry in Orbis under the assumption that these belong to small firms that are simply not listed. In the robustness section, we present results where we limit the analysis to firms that we can locate withing Orbis, thus making sure that no intra-firm trade is counted as a "real" trade (but at the cost of losing a significant number of observations).

Whereas some exchanges directly connect buyers and sellers, others route allowance trades via their own PHA or the PHA of an intermediary. For example, all transaction made on BlueNext appear twice in our data—as a sale to BlueNext as well as a purchase from BlueNext. Similarly, purchases via brokers, market makers and firms serving as clearinghouses are doubled in this way (the selling firm transfers allowances to the intermediary, which then transfers them to the buyer). To avoid double counting, we remove all transactions in which the BlueNext, Climex and NordPool exchanges act as a buyer, as well as transactions bought by a set of known brokers, market makers and clearing houses.[10]

We further remove 8,457 trades carried out by a single trader that was later convicted of VAT tax fraud.[11] This leaves us with 326,873 transactions in total. There are 7,221 unique OHAs and 3,435 unique PHAs, belonging to 6,968 different firms, with at least one active purchase in our sample period. In 87% of all transactions, the purchasing account is a PHA. We address the sensitivity of our results to these and additional sample restrictions in a series of robustness tests in Section 4.

We denote an allowance transfer by $x_{bf,bc,sf,sc,t}$ (in tCO_2), with the subscripts defined as follows: *bf* refers to the firm that makes the purchase ("buying firm"), *bc* is the "buying" country where the firm is located, and *sf* and *sc* refer to the seller firm and seller country, respectively. The time subscript *t* marks the date of the transfer.

To reduce the computational burden of our analysis, we aggregate our data to the country-level on the selling side and to the yearly level on both sides of the trade.[12].

$$X_{bf,bc,sc,y} = \sum_{sf \in sc} \sum_{t \in y} x_{bf,bc,sf,sc,t} \tag{1}$$

We then build a trade matrix where we associate each firm, for which we observe at least one allowance purchase, with a potential selling country participating in the EU ETS.[13] Since we are primarily interested in the behavior of firms covered by the EU ETS, we drop all trades in which the buyer is located outside the EU ETS. We furthermore aggregate all remaining transactions in which the seller is outside the EU ETS into one foreign account. Our sample contains a total of 6,968 unique firms with at least one active purchase in our sample period. After removing countries with insufficient trades, this gives us a total of 28 possible seller countries per year (for each firm).[14] This results in a trade matrix of 1,629,730 cells, which we populate with the EUTL transactions data according to (1).

In order to assess a potential home bias within allowance trading, we construct an "Intra"-trade dummy that is equal to one if the buying firm is located in the selling country, and zero otherwise:

$$INTRA_{bf,bc,sc,y} = \mathbb{1}\{bc = sc\} \tag{2}$$

We use the 2016 release of the World Input-Output Tables (WIOD) to measure trade patterns in goods and services between countries. This data set covers all countries in our sample and provides bilateral—including intranational—trade flows across 56 sectors that include food, manufacturing and services.[15] We aggregate the data to the importer-exporter-year level.

[9] As in Jaraitė-Kažukauskė and Kažukauskas (2014), we aggregate the data to the country-firm level. This means that if a firm has accounts in N countries, we treat it like N different firms. Contrary to intra-firm trade within a country (which we exclude from our analysis), cross-country trade within the same firm is not excluded. However, if firms transfer allowances between subsidiaries located in different countries, this will inflate cross-border trade and thus reduce our estimate for the home country bias.

[10] We identified these intermediaries based on their name, or if they appeared on the list of clearing houses for an exchange. Specifically, we removed purchases made by Vertis, SendeCO2, Wallich & Matthes, STX, European Commodity Clearing, UBS Clearing & Execution Services, ABN AMRO Clearing Bank, Stichting Emissiebeurs Clearing, Beaufort Asset Clearing Services, LCH.Clearnet Limited, Clear Plc, Carbon Clear Limited, CLEAR ENERGY TWO SRL. We thank Aurelie Slechten and Estelle Cantillon for their support in identifying intermediaries.

[11] This trader was Mr. Klapucki; more information about the VAT tax fraud is provided below.

[12] The EUTL database lists the date when the allowances were actually transferred. For forward trades, the date when the deal was made therefore differs from *t*. Aggregating the data to the yearly level removes this problem for end-of-year forward contracts, but not for trades that clear in a different calendar year.

[13] We focus on allowance purchases. Naturally, the total number of purchases has to equal the total number of sales. However, it is possible that aggregating over the buyer rather than the seller side would change the results. We address this issues in section 4 below.

[14] The EU ETS started out with 25 countries in 2005. In 2007, Romania and Bulgaria joined the EU (and thus the EU ETS). Norway, Iceland and Liechtenstein linked their domestic cap-and-trade systems to the EU ETS in 2008. Iceland did not purchase allowances during our sample period, and the number of transaction in the cases of Malta and Liechtenstein are very limited. Croatia joined the EU and the EU ETS in 2013, but did not start trading in a significant dimension before 2014. For these reasons, we removed these four countries and work with 27 ETS countries.

[15] The WIOD is a standard dataset that is regularly used in the trade literature, e.g., Fajgelbaum and Khandelwal (2016) or Costinot and Rodríguez-Clare (2014). For a detailed description, see Timmer et al. (2015).

Table 1
Descriptive Statistics Key Variables.

Variable	Full Sample Margin	Mean	Std. Dev.	Min.	Max.	Obs.	Units
			Dependent Variable				
Purchases CO2 allowances	Overall	15,329	673,069	0	293,561,775	1,629,730	tCO2
	Intensive	812,517	4,833,840	1	293,561,775	30,746	tCO2
	Extensive	0.019	0.136	0	1	1,629,730	–
			Explanatory Variables				
INTRA	Overall	0.038	0.190	0	1	1,629,730	–
	Intensive	0.398	0.489	0	1	30,746	–
Log imports goods & services	Overall	7.775	2.351	0.090	14.834	1,629,730	millions of US dollars
	Intensive	10.884	2.703	1.094	14.834	30,746	millions of US dollars

Table 1 contains descriptive statistics of the key variables used in the regression analysis. The "Overall" sample represents the unrestricted dataset; the sample labeled as "Intensive" only contains positive purchases, and "Extensive" gives information about the unconditional probability of an active trade connection between a firm and a selling country.[16] The probability of observing a positive purchase volume for any given firm (*bf*)-country (*sc*) pair in a given year is 1.9%. The data reveal a substantial variation in the number of traded allowances across the sample, with annual purchases from a specific country ranging to zero to almost 300 million allowances. Many of the largest volumes are purchased by institutional traders using PHAs. In Table A1 in the Appendix, we present the descriptive statistics for the sub-sample consisting only of transactions among OHAs.

Before moving on to the regression analysis in the next section, we present a descriptive indication of the presence of a home bias in the EU ETS allowance transaction data. In order to obtain a meaningful descriptive measure for the home bias on an aggregate level, we have to correct for a country's market share (in our regressions, this is done by including country-year dummies). For example, German firms can be expected to trade more domestically than Austrian firms, simply because German firms own a larger share of the initial allocation. Corrected for the allocation share, the relative home bias for country *bc* is given by

$$RHB_{bc} = \left(\frac{\sum_y \sum_{bf \in bc} \sum_{sc=bc} X_{bf,bc,sc,y}}{\sum_y \sum_{bf \in bc} \sum_{sc} X_{bf,bc,sc,y}} \right) \Bigg/ \left(\frac{\sum_y \sum_{bf \in bc} A_{bf,bc,y}}{\sum_y \sum_{bf} A_{bf,bc,y}} \right). \tag{3}$$

The numerator represents the home market share of country *bc*'s total purchases, and the denominator is the share of this country's allocations in the total emissions cap. In the absence of a home bias (and any other distortion that could affect trade), RHB_{bc} would be unity for each country, whereas a greater value implies a home country bias. Fig. 1 shows the inverse of RHB_{bc} (such that the measure falls between 0 and 1) for the full sample as well as for the sub-sample involving trades among OHAs only, thus removing all trades that are unrelated to compliance.[17] The inverse relative home bias of all countries is well below one in all samples, suggesting a strong home bias in the data. The home bias is stronger for OHAs, which points to the fact that an important share of international allowance trades are carried out by PHAs.

2.3. Econometric model

Our regression setup builds on a parsimonious specification of the gravity equation, which has been extensively used in the economic literature to model bilateral economic relationships. Applications include flow variables such as bilateral trade in goods and services (e.g., McCallum, 1995; Wolf, 2000) or financial assets (e.g., Aviat and Coeurdacier, 2007). The gravity equation has also been used to model migration or genetic distance between ethnic groups (e.g., Beine et al., 2016; Spolaore and Wacziarg, 2009). We use the gravity framework to model bilateral CO_2 allowance purchases as a function of a set of categorical variables. Besides the INTRA dummy, which denotes domestic allowance purchases, we include seller-country- and buyer-country-specific time-fixed effects to control for trade partners' GDP, emissions, allowance allocation and any other potential confounding effects that vary over time and/or country. For the regressions on the intensive margin of trade, we also include firm-level fixed effects to control for any systematic heterogeneity in the trading behavior of individual firms.

In our preferred specification, the identification of the effect of trading domestically is based only on the within-firm variation over time. This variation might stem from the extensive margin (i.e., firms may change the number of countries from which they purchase allowances in a given year) or from the intensive margin (i.e., changes in the trade volume within existing trade relationships).

[16] The decomposition of trade flows into extensive and intensive margins builds on the seminal work of Helpman et al. (2008).
[17] Since many firms use PHA's to collect and pool allowances assigned to different installations, focusing on trades by OHAs removes some of the compliance-related trades as well. In other words, the OHA-supsample contains only compliance-related trades, but not all of them.

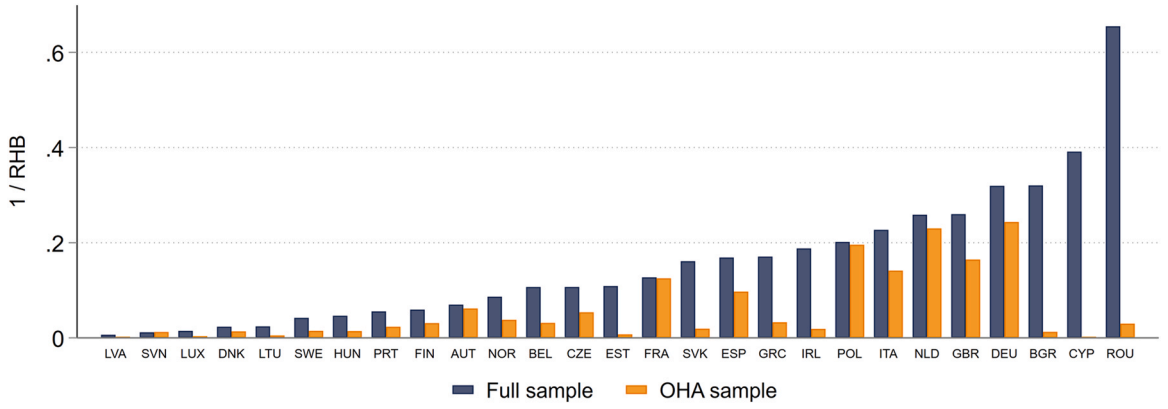

Fig. 1. Inverse home bias by country. Note: The dark bars show the results for full sample and the light bars for the operator account subsample. Because the figure shows the inverse home bias, the actual home bias decreases from left to right.

We carry out our regression analysis at the firm(buyer)-country(seller) level using the following gravity equation:

$$ln(X_{bf,bc,sc,y}) = \beta_0 + \beta_1 INTRA_{bf,bc,sc,y} + \beta_2 \lambda_{bc,y} + \beta_3 \lambda_{sc,y} + \beta_4 \gamma_{bf} + ln(\eta_{bf,bc,sc,y}) \quad (4)$$

The dependent variable represents allowance trades as defined in Eq. (1), either overall, or on the intensive (i.e., conditional on $X_{bf,bc,sc,y} > 0$) or the extensive margin (i.e., the probability of a trade taking place between firm *bf* and country *s* in year *y*). The dummies $\lambda_{bc,y}$ and $\lambda_{sc,y}$ are country-year fixed effects for the buyer and the seller country, respectively, and γ_{bf} are firm-level fixed effects. The unobservable determinants of certificate trade are captured by the error term, with $E[\eta_{bf,bc,sc,y}|INTRA_{bf,bc,sc,y}, \gamma_{bf}, \lambda_{bc,y}, \lambda_{sc,y}] = 1$.

Conditional on the fixed effects (and any other covariates, if included), the null hypothesis is that $\beta_1 = 0$, whereas $\beta_1 > 0$ indicates the presence of a systematic home bias, and therefore of transactions costs that are lower when trading within a country than across borders.

Note that estimating the log-linearized gravity equation would lead to a substantial loss of observations in our context, since many firm-country pairs have no transactions in a given year, and thus would restrict the analysis to the intensive margin of trade. Furthermore, the log-linearized version may lead to inconsistent estimates if allowance trade is heteroskedastic, because the expected value of the logarithm of a random variable depends both on its mean and its variance. To preserve the overall margin of trade and to obtain consistent coefficient estimates in the presence of heteroskedasticity, we employ the Poisson Pseudo-Maximum Likelihood (PPML) estimator proposed by Santos Silva and Tenreyro (2006) and implemented by Correia et al. (2019), (2020)).[18]

To estimate the extensive margin, we estimate (4) using a Probit model.

3. Results

We start by presenting our main results and then investigate potential mechanisms to explain the home bias.

3.1. Average home bias

Table 2 shows the results from the baseline model, using the allowance transaction data of the full sample and focusing on purchases. Column (1) shows the unconditional bi-variate regression of the overall purchase volume on the dummy for intra-national trade. This unconditional regression does not control for any potentially confounding effects that vary by country and year, and which could co-determine the extent and pattern of allowance trade. Moving from left to right across columns (1) to (3), we subsequently add buyer- and seller-country fixed effects as well as buyer- and seller-country-year fixed effects. Adding fixed effects reduces the risk of omitted variable bias, but reduces the sample variation.

[18] The exponentiated version of (4) can be written as

$$X_{bf,bc,sc,y} = c_0 \cdot e^{\beta_1 INTRA_{bf,bc,sc,y}} \cdot e^{\beta_2 \lambda_{bc,y}} \cdot e^{\beta_3 \lambda_{sc,y}} \cdot e^{\beta_4 \gamma_{bf}} \cdot \eta_{bf,bc,sc,y}$$

If the variance of $\eta_{bf,bc,sc,y}$ depends on the regressors, then $ln(\eta_{bf,bc,sc,y})$ will depend on (the log of) these regressors too. Because permit purchases cannot be negative by definition, this means that as $X_{bf,bc,sc,y}$ approaches zero, the variance of $\eta_{bf,bc,sc,y} = X_{bf,bc,sc,y} - E[X_{bf,bc,sc,y}|INTRA_{bc,sc}, \gamma_{bf}, \lambda_{bc,y}, \theta_{sc,y}]$ has to approach zero as well, such that $Var(\eta_{bf,bc,sc,y})$ may well be related to the regressors. For more details, see Santos Silva and Tenreyro (2006).

Table 2
Home bias in allowance trade, 2005–2013.

Dependent variable:	Poisson PML					Probit
Allowance purchases	Overall (1)	Overall (2)	Overall (3)	Intensive (4)	Intensive (5)	Extensive (6)
INTRA	2.940**	1.974**	1.865**	−0.003	0.806**	0.138**
	(0.315)	(0.206)	(0.200)	(0.095)	(0.096)	(0.017)
Constant	9.088**	10.254**	10.788**	14.112**	14.947**	
	(0.157)	(0.113)	(0.107)	(0.057)	(0.058)	
Buyer-country (BC) FE	no	yes	–	–	–	–
Seller-country (SC) FE	no	yes	–	–	–	–
BC-year FE	no	no	yes	yes	yes	yes
SC-year FE	no	no	yes	yes	yes	yes
Firm FE	no	no	yes/no	no	yes	yes/no
Observations	1,623,906	1,623,906	1,623,906	30,031	27,603	1,623,906

Note:' $p < 0.10$, *$p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimation in column (6), the marginal effect is reported and the constant omitted. Including firm FE is inconsequential in columns (3) and (6).

We find a positive and significant coefficient of the dummy variable for intra-national trade. For example, the coefficient in column (3) implies that the average firm's total purchase volume on the home market is ($e^{1.865}$ =) 6.5 times larger than the total purchase volume from the average foreign country, implying that the average purchase volume is 550% larger within than across countries. The fact that the coefficient on INTRA declines from column (1) to (3) suggests the presence of an omitted variable bias in the unconditional regression results that is corrected by including fixed effects on the country-year level.

In columns (4) and (6), we decompose the overall trade volume into an intensive and extensive margin, respectively. For the extensive margin, we report the marginal effects (i.e., the change in the probability if the INTRA-dummy switches from 0 to 1). The coefficient on INTRA is not statistically different from zero on the intensive margin, indicating that, conditional on a trade taking place, domestic trades are not larger in volume than international trades. On the extensive margin, however, the analysis again reveals a strong home bias: The probability of observing an active trade connection with another firm in the home market is on average 13.8 percentage points larger than with firms located in any foreign country. Given that the probability to observe an active trade connection between the average firm-country pair is only 1.9% (see Table 1), this result is substantial.

In column (4), we additionally include firm fixed effects for the intensive-margin regression.[19] The home bias is now positive and significant on the intensive margin as well, implying that unobserved heterogeneity across firms matter for the trade volume of existing trade relationships. For example, if (many) small firms tend to trade nationally and in small amounts, and (fewer) large firms engage in both national and international trades involving large volumes, then a failure to control for firm size will lead to a smaller home bias on the intensive margin. This explanation is consistent with the descriptive statistics of trade: The total trade volume—aggregated over our sample period—of the average firm that only trades at home is about 425,000 allowances, whereas the total trade volume of the average firm that (also) buys allowances from abroad is more than ten times larger.

For completeness, Table A2 in the Appendix reports estimates for the home bias after aggregating the data to the country-pair-year level. The overall home bias is similar to that in Table 2, but, at the aggregated level, the intensive margin becomes the dominant factor behind the home bias.[20] This contrasts with the regressions on the firm level, where the extensive margin dominates, and highlights the fact that we cannot draw conclusions on firm behavior from aggregate data. Disaggregation is particularly important in our context, because we are explicitly interested in firm-specific heterogeneities that allow us to draw conclusion about the equalization of marginal abatement costs across firms.

Our results document a substantial home bias in international allowance trade. In the absence of transportation costs and other forms of explicit trade costs, and considering that allowances are perfectly homogenous, one possible interpretation for the results in Table 2 is the existence of informational frictions associated with the participation in international allowance trade.

3.2. Heterogeneity

It is important to note that the presence of trade costs (and thus of a home bias) per se does not lead to a distortion as long as these costs are the same for all polluters. In this case, marginal abatement costs will still be equated because all firms face the

[19] For the overall and the extensive margin, this is of no consequence given that the trading matrix is balanced and thus there is no correlation between the account id and the presence of the INTRA-dummy. In other words, the unobserved and time-invariant heterogeneity that would be captured by the firm FE is orthogonal to the error term. For this reason, the results with and without firm-level FE are the same for these unconditional regressions. However, when the intensive margin is estimated, or if the INTRA dummy is interacted with a variable that varies over firms, including firm FE matters.

[20] The reason being that the number of zero allowance imports between country-pairs is very low.

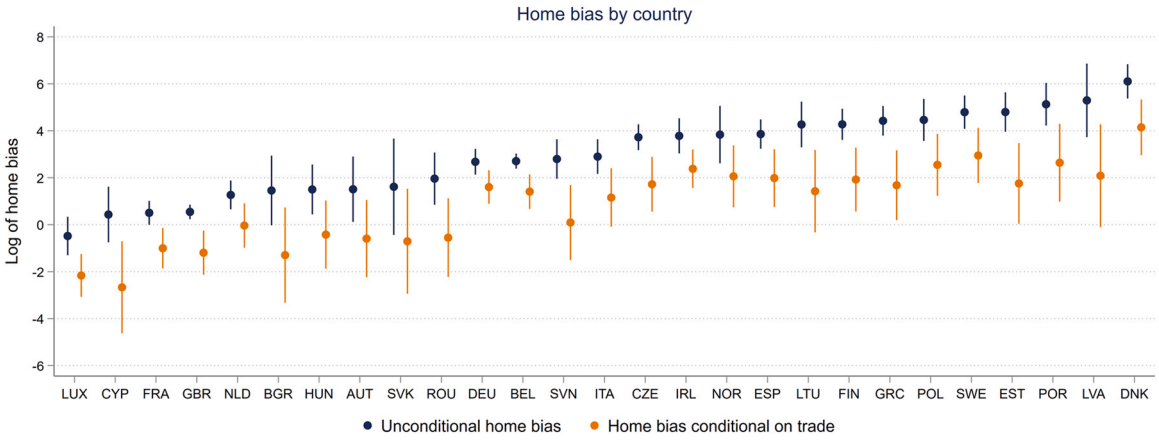

Fig. 2. Country-specific home bias (dots) and 95% confidence intervals. Note: The dots show the point estimate of the coefficient on the INTRA-dummy interacted with the respective country dummy, and the bars represent 95% confidence intervals. Countries are labeld by Alpha-3 code. The null hypothesis of equal home bias is rejected at $p < 0.001$.

same total allowance costs (which consist of the price plus trading costs), such that market efficiency is achieved. However, if trading costs differ between market participants, then marginal abatement costs are not equalized, and, as a consequence, the market is not efficient. In the following, we present evidence for heterogeneous transactions costs along three dimensions: (i) firm location (countries), (ii) firm size and (iii) industrial sector.

We estimate country-specific coefficients by interacting country-dummies with the INTRA-dummy. Fig. 2 shows the point estimates and confidence intervals in black (the corresponding regression output is shown in Table A3). The home bias is statistically significant for all countries that participate in the EU ETS, with the exception of Luxembourg and Cyprus. The results imply that substantial differences exist in the severity of cross-border friction across firms, depending on their location. Since transactions costs in international allowance trade differ across countries, total permit costs (and thus marginal abatement costs) are not equalized across firms within the EU ETS.

The grey bars denote the home bias based on a regression that additionally controls for the trade in goods and services (this will be discussed in more detail below). This "conditional" home bias is much smaller, but the standard deviation of the point estimates remains virtually unchanged (1.75 vs. 1.71), such that differential integration into trade networks is unlikely to explain the country differences.

Table 3 shows the results from a linear regression of the country-specific home bias on population, surface area, GDP per capita and the average distance to the other ETS countries. This regression is limited in power due to the small number of degrees of freedom, but it does explain around 38% of the country heterogeneity. The results indicate that the home bias increases with the surface area and the average distance to other countries, but does not depend on population size or income.

The home bias may also depend on firm size. For the present context, we approximate a firm's size with the total allowance purchase volume during our sample period. The regression results that include the allowance trade volume, by itself and interacted with the INTRA-dummy, are shown in Table 4. In columns (4)-(6), we also estimate regressions where we divide firms into those that have a high trading volume (>90th percentile) and those with a medium trading volume (50th to 90th percentile), relative to the omitted category (<50th percentile). The home bias decreases in the total allowance trade volume, suggesting that larger firms (which tend to trade more) face smaller international trade frictions. This effect is driven by the extensive margin, whereas the coefficient on the interaction term is not statistically significant for the intensive margin. These results are qualitatively consistent with the results reported by Jaraitė-Kažukauskė and Kažukauskas (2014), who find that larger

Table 3
Determinants of the country-specific home bias.

Dependent Variable:	Country-level home bias	
	Coef.	SE
Ln(GDP per capita)	−0.431	(0.525)
Ln(population)	−0.652	(0.434)
Ln(av.distance EU)	36.591′	(19.907)
Ln(surface area)	0.845′	(0.442)
R^2	0.384	
Obs.	27	

Note:′ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Robust standard errors are reported (in parentheses). The dependent variable is the size of the home bias of a given country. Log average distance EU is the log of the average distance of a country to all other EU countries.

Table 4
Home bias by total purchase volume.

Dependent variable:	Poisson PML		Probit	Poisson PML		Probit
Allowance purchases	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	5.920 **	− 0.662	0.240**	3.404 **	− 0.136	0.167**
	(0.998)	(1.127)	(0.030)	(0.195)	(0.155)	(0.013)
INTRA × Log total purchase volume	− 0.226 **	0.081	− 0.001 **			
	(0.060)	(0.064)	0.240**			0.167**
INTRA × Highvol			(0.000)	− 1.583 **	0.965 **	(0,013)
				(0.254)	(0.163)	(0.003)
INTRA × Medvol				− 0.882 **	0.376 *	− 0.006 **
				(0.162)	(0.150)	(0.001)
Constant	13.385 **	14.958 **		13.381 **	14.953 **	
	(0.098)	(0.056)		(0.105)	(0.058)	
Observations	1,569,572	27,603	1,623,906	1,582,840	27,603	1623,906

Note:' $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Log total purchase volume is the logged value of the account-specific total allowance purchases over the sample period, 2005–2013. Highvol is a dummy equal to one if the firm's total purchase volume is greater than the 90th percentile; Medvol is a dummy equal to one if the purchase volume is between the 50th and 90th percentiles. All regressions include BC-year, SC-year and firm fixed effects.

firms face smaller overall transactions costs. To the extent that firm size may differ across countries, these results could also explain a part of the inter-country heterogeneity that is not captured by the variables in Table 3.

Next, we focus on industrial sectors. We start by interacting sectoral dummies (based on the first digit of the NACE rev.2 classification) with the INTRA dummy. The results indeed imply a sectoral variation; for the results, see Table A4.[21] To further analyse if the home country bias in the EU ETS is driven by a "home industry sector bias" (i.e., a situation in which market participants are more likely to trade within than across different industry sectors, ceteris paribus), we construct a firm(buyer)-country(seller)-industry(seller) trade matrix. This allows us to analyze both types of bias simultaneously. We classify industries according to the 2-digit NACE classification and adjust the gravity equation as follows:

$$ln(X_{bf,bc,bi,sc,si,y}) = \beta_0 + \beta_1 INTRA^C_{bf,bc,sc,y} + \beta_2 INTRA^I_{bf,bi,si,y} + \beta_3 \lambda_{bc,y} + \beta_4 \lambda_{sc,y} + ln(\eta_{bf,bc,bi,sc,si,y}) \quad (5)$$

Here, $X_{bf,bc,bi,sc(si),y}$ denotes the overall trade volume between a buyer firm *bf* (located in the country *bc* and associated with the industry sector *bi*) and the seller industry *si*, located in the seller country *sc*, in a given year, *y*:

$$X_{bf,bc,sc(si),y} = \sum_{sf \in sc(si)} \sum_{t \in y} x_{bf,bc,bi,sf,sc,si,t} \quad (6)$$

The dummies $INTRA^C$ and $INTRA^I$ denote trades that take place within the same country and the same industry, respectively. As before, we include country-year fixed effects for the buyer and the seller country, respectively, and we estimate the regression in exponentiated form using PPML. The unobservable determinants of certificate trade are captured by the error term, η.

Table 5 shows the results of regressing firm-level trades on this trade matrix. We see that there is a strong within-industry bias, but that accounting for this does not significantly reduce the home country bias.[22] This implies that while firms do trade allowances more heavily with partners in the same industry (which we find interesting on its own), the sectoral composition cannot explain the observed differences in the home country bias.

3.3. Underlying mechanisms

Our results indicate the presence of a strong home bias that differs across firm location, size and industrial clasification. In this subsection, we focus on two potential mechanisms that can explain this result: Existing trade networks in goods and services, and fixed vs. variable costs of allowance trade.

If allowances could only be bought and sold on exchanges (all of which have the same allowance price due to arbitrage), our results would imply differential transactions costs in accessing exchanges. In this case, all firms would face the same permit price but differ concerning their transactions costs such that the marginal abatement costs will not be equalized. However, the presence of a home bias even in countries that do not have exchanges where EUAs are traded—(the majority of the countries in our sample), suggests that many allowance transfers occur via brokers or bilaterally between the two involved parties ("over the counter"). Although there is no official information as to what proportion of allowances are traded on vs. off exchanges, (broker-

[21] Note that this regression can only be carried out for firms for which we have NACE information, which is a subset of the firms that we are able to locate in Orbis. However, the main message of the table is not the level of the home bias (which is higher than for the full sample), but the variance of it across sectoral classification.

[22] Again, we note that this regression only involves the firms for which we have NACE information, such that the overall home bias is different to our base estimate in Table 2.

Table 5
Home bias across country and industry: Country-industry trade matrix.

Dependent Variable:	Allowance purchases		
	Poisson PML		
	(1)	(2)	(3)
$INTRA^C$	2.755 **		2.686 **
	(0.224)		(0.181)
$INTRA^I$		3.271 **	3.217 **
		(0.303)	(0.241)
Obs.	5,953,333	5,953,333	5,953,333

Note:' $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. $INTRA^C$ is a dummy variable that is one if a given firms buys EU ETS certificates nationally and zero otherwise. $INTRA^I$ is one if a given firm buys EU ETS certificates within the same industry (two digit Nace rev. 2 classification). All regressions refer to the overall margin of allowance trade and include BC-year and SC-year FE.

supplied) evidence exists suggesting that many transactions in our sample period take place outside an organized market (e.g., Ellerman et al. (2016) or World Bank (2012), p. 33).[23] Market participants most likely engage in bilateral trade in order to avoid the fees and implicit costs associated with international exchanges. It is not clear how the transactions costs in bilateral trade are divided between seller and buyer, as this depends on their relative bargaining power (Stavins, 1995). However, for cost-minimizing firms, the wedges between bilateral total allowance costs and exchange prices cannot differ by more than the costs associated with accessing international exchanges (see section 2.1).

Bilateral trade is characterized by information asymmetries, e.g., due to search frictions or contract uncertainty (Chaney, 2014). This suggests that personal trade networks may be important in allowance trade. Potential buyers and sellers of EU allowances may learn about each other through existing trade relationships in the goods and service markets. Since firms have, on average, a more extensive domestic trade network, informational transactions costs are lower within countries than across borders. Given the well-documented home bias in goods and services (McCallum, 1995), which is of comparable size as the home bias documented here, it is thus possible that the home bias in the EU ETS is simply a different manifestation of the trade pattern in goods and services.[24]

To test this hypothesis, we re-run our regression specifications of Table 2, but add the total yearly bilateral trade volume in goods and services between countries as a control variable. The first three columns of Table 6 shows the results for the specification including the most restrictive set of fixed effects. Focusing on the overall purchase volume in column (1), we find that the magnitude of the home bias is reduced by about two thirds.[25] This suggests that existing trade networks for goods and services can explain an important part of the home bias in the EU ETS. The coefficient estimates further imply that this mechanism works mostly via the extensive margin, since the home bias on the intensive margin remains about the same as without controlling for trade in goods and services. This is intuitive, given that the information asymmetry can be expected to influence the matching of trading partners, but not necessarily the trading volume once a match has been established. Furthermore, we note that controlling for the trade pattern in goods and services reduces the *level* of the home bias in allowance trade. However, as shown by the grey bars in Fig. 2 above, these trade patterns do explain the country-specific differences we observe in the home bias for allowance trade.

An alternative, or complementary, mechanism that could lead to a home bias in allowance trade are fixed foreign market entry costs (Chaney, 2014; Rauch, 1999; Melitz, 2003). To investigate this possibility, we construct a binary variable, $EST_{bf,bc,sc,y}$, that is one if buying firm *bf* has already established a trade connection with seller country *sc* in any year prior to *y*, and zero otherwise:

$$EST_{bf,bc,sc,y} = \mathbb{1}\left\{\sum_{t=2005}^{t=y-1} X_{bf,bc,sc,y} > 0\right\} \tag{7}$$

Columns (4)-(6) in Table 6 shows the results of including this dummy variable in the regression. We find that having previously traded with a counterparty in a given country significantly increases a firm's probability for further trades along both margins. Furthermore, the coefficient on the interaction term implies that the overall home bias is significantly smaller for firm(buyer)-country(seller) pairs that have already traded before, due to a reduction along the extensive margin. Having a previously established trade connection increases the probability of a trade by 9.2% points while reducing the home bias by 1.3% points.

If cross-border transactions costs occur predominantly when establishing a new trade relationship, the home bias could be an initial phenomenon that diminishes over time as more trade connections have been formed. To test this hypothesis, we

[23] The EUTL data only contain the transfer amounts and details about the involved parties, but no information about the price or whether the trade took place on an exchange. Note also that it is not possible to infer the number of off-exchange trades by subtracting the exchange-traded volume from total transactions, since some exchanges settled forward contracts financially rather than physically.

[24] The home bias in goods and services ranges from 2 to 10, depending on the country (Anderson and Wincoop, 2003), which spans our estimate of 6.5.

[25] This is derived as $\frac{e^{1.865} - e^{0.819}}{e^{1.865}} = 0.65$.

Table 6
Underlying mechanisms.

Dependent variable: allowance purchases	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	0.819′	0.866 **	0.016 *	2.456 **	0.704 **	0.114 **
	(0.455)	(0.253)	(0.008)	(0.253)	(0.227)	(0.009)
Log imports in goods & services	0.249 *	−0.014	0.008 **			
	(0.097)	(0.054)	(0.001)			
INTRA*EST				−1.404 **	0.057	−0.013 **
				(0.277)	(0.243)	(0.001)
EST				2.518 **	0.504 **	0.092 **
				(0.129)	(0.095)	(0.005)
Observations	1,623,809	27,603	1,623,906	1,599,332	27,603	1,623,906

Note:′ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For Probit estimations, the average marginal effects are reported. All regressions include country-year and firm FE. For the definition of the EST dummy, see main text.

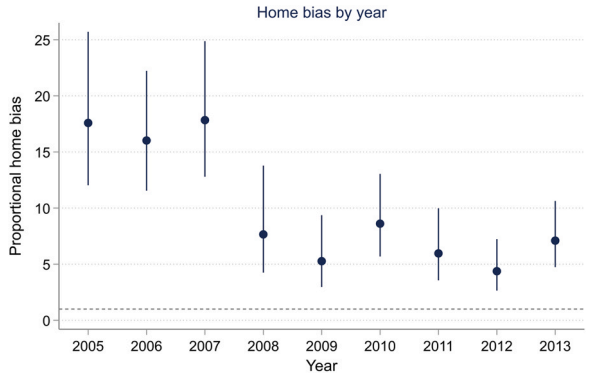

Fig. 3. Home bias (dots) over time and 95% confidence intervals. Note: Results are based on the estimates presented in column (1), Table A5 in the Appendix. The coefficients are shown in exponentiated form, resulting in a proportional measure of home bias. A value of one indicates no home bias (see dotted line).

create year-dummies and interact them with the INTRA-dummy. Figure 3 shows the point estimate and confidence intervals for the overall home bias over time; the full results are shown in Table A5 in the Appendix. The home bias has decreased but not disappeared over time and is still significant in 2013, the ninth year of the EU ETS.[26] Furthermore, we find that the home bias is much higher in the first phase relative to later years (to see this, refer to Table A10 in the Appendix), which may be explained by overall market liquidity. Especially at the beginning of this first pilot phase, very little allowance trade took place (Ellerman et al., 2016).

The reduction in the home bias over time is consistent with an increasing number of firms having incurred the fixed cost of foreign market entry. However, it is important to keep in mind that other—non-exclusive—possible explanations exist for the results in Fig. 3. For example, a decrease in the home bias over time could also be explained by an ongoing process of market integration across the EU (Bergstrand et al., 2015). Unfortunately, our data does not allow us to test for this hypothesis.

4. Robustness tests

To assess the robustness of our results, we conduct a series of tests using different sub-samples of the data. In this section, we discuss the qualitative findings of these tests. The corresponding tables can be found in the Appendix.

We were not able to associate all accounts in EUTL within the Orbis database, especially not PHAs. To ensure that the home bias is not driven by "invisible" intra-firm trade between accounts that in fact belong to the same firm, but for which we cannot establish a connection via Orbis, we have re-estimated our model using only accounts for which we find information in Orbis. Columns 1–3 in Table A6 presents the results from this regression. The resulting home bias is very similar to the regressions based on the full sample, implying that it is not driven by unobserved intra-firm trade. As is the case for the overall sample, controlling for the trade in goods and services reduces the home bias, but it does not eliminate it (columns 4–6).

[26] The null hypothesis of a time-invariant home bias is rejected at $p < 0.001$. We cannot reject the null hypothesis of equal coefficients within phase 1, but they differ for the years 2008–2013 ($p < 0.001$).

In our baseline specification, we have aggregated all trades to the firm level. However, it is possible that firms belonging to the same owner pool allowances among themselves. To control for this possibility, we aggregate the data to the level of the Global Ultimate Owner (GUO) as defined by the Orbis database. Table A7 presents the estimates. The uncondtional results are qualitatively similar to the regressions involving the firm-level sample, suggesting that trade within firms owned by the same GUO are not responsible for the home bias. On the other hand, controlling for the trade in goods and services removes the home bias (or at least we cannot reject the null hypothesis of no home bias), suggesting that allowance trade is more closely aligned with "regular" trade when aggregated to a larger firm concept.

The EU ETS covers large installations in energy-intensive sectors. These installations are assigned an Operator Holding Account (OHA), but anyone can open a Person Holding Account (PHA) and trade allowances and in fact a large share of the allowance trade occurs via PHAs. As discussed above, some of the trades involving PHAs are carried out by firms owning installations covered by the EU ETS that find it convenient to centrally collect and manage the free allocation of their OHAs. However, other allowance trades involving PHAs are unrelated to emissions compliance. Many financial institutions have included allowances into their portfolio as an additional asset. The existence of a home bias for trade that is primarily motivated by hedging or speculation does not necessarily imply an inefficiency in terms of emissions abatement as long as compliance trade is not subject to this friction.

Furthermore, there is evidence that some allowance trade took place with the purpose of perpetrating a value added tax (VAT) fraud (Efstratios, 2012; Nield and Pereira, 2016). These tax fraud schemes exploited the fact that the EU levies a VAT on the sale of emission allowances if it they are traded within a country, but that sales across borders are exempt from VAT.[27] For the tax fraud scheme to work, the trader that owes the VAT payment to the respective national government has to disappear (this firm is referred to as the "missing trader"). Since OHAs represent physical installations owned by firms that can easily be located, VAT fraud necessarily involves a PHA on at least one side of the trade.

In order ensure that our results are not driven by transactions that are either legitimate trades unrelated to compliance, or artificial trades in the context of VAT fraud, we restrict our analysis to transactions where both sides of the trade are OHAs. Table A8 shows the corresponding regression results. Again, we find strong evidence for a home bias (columns 1–3). For this subsample, the coefficient on the intensive margin is positive even without including firm fixed effects, which is likely due to the absence of the firms with the largest trading activity, which tend to be PHAs. Furthermore, we find no statistical evidence for a home bias within OHAs once we control for the trade in goods and services (columns 4–6), as was the case for the GUO-level regressions. Since OHAs belong to firms that produce physical output, this finding is consistent with the idea that allowance trade is facilitated by pre-established networks among firms that are in an upstream / downstream or horizontal relationship.

Since the VAT fraud was particularly widespread in France, and it occurred mostly during Phase II of the system (Nield and Pereira, 2016), we re-run the analysis (a) after excluding all trades where either the buying or selling account holder is located in France, and (b) after restricting the sample to the first period (2005–2007) or the years afterwards (2008–2013). The results are shown in Tables A9 and A10, respectively. The qualitative nature of the results remains unchanged. Note also that since VAT fraud necessarily involves international transactions (in addition to domestic ones), widespread VAT fraud will likely decrease the extent of the home bias, not exacerbate it. Indeed, the estimate for the overall home bias is larger when excluding France (2.146 vs. 1.865), but it is not clear whether the difference is statistically significant. The results in A10 furthermore show that the home bias was significantly larger during the first phase than during the later years, which is consistent with Fig. 3.

In order to check to what extent the home bias is driven by brokers and exchanges, we re-build our trading matrix after excluding sales from these intermediaries (in order to avoid double-counting, purchases by brokers and exchanges have been removed already in the baseline analysis). Excluding brokers and exchanges, to the extent that we can actually identify them in the data, does not change the results (see Table A11), indicating that they are not a driving force behind the home bias in allowance trade.

Last, we re-run our regression analysis for the sales (rather than purchases) of allowances by aggregating our transaction data to the firm(sf)-country(bc)-year(y) level. Even though the underlying transaction data is the same, differences in the results could arise due to differences in aggregation. The results are shown in Table A12, and they are again very similar to those from the base model.

5. Conclusions

In this paper, we provide evidence for a home bias in allowance trading in the EU ETS during the years 2005–2013. The home bias occurs along both margins of trade, persists even in the ninth year of the market and is robust to the use of different subsamples. Since allowances are perfectly homogenous and not associated with transportation costs, these trading frictions point to the presence of informational transactions costs that increase across borders. The home bias becomes smaller if we control

[27] A typical mechanism for VAT fraud involves a carousel of firms located in different countries, as in the following example: Firm a located in country A sells allowances to firm b1 located in country B. Because this is an international sale, it is exempt from the VAT. Next, firm b1 sells the allowances to firm b2, which is also located in country B. Firm b1 charges the VAT to firm b2, but never forwards it to the tax agency in B. Firm b2 then sells the allowances back to firm a, and because this is again an international transaction, the tax authorities in B reimburse it for the VAT. If all three firms belong to the same criminal organization, the allowances can be sent around in a circle many times. The financial gains accrue because firm b2 receives the VAT reimbursed from the tax authority in B, but the tax authority never receives this tax from firm b1, which disappears (a "missing trader"). The system has since been reformed such that this type of fraud is no longer possible.

for trade patterns in goods and services, for which a well-established home bias exists. This suggests that firms use their existing trade networks to overcome informational costs in allowance trading. However, the home bias persists even when controlling for the trade pattern in goods and services, indicating that this is not the only explanation at least when looking at the whole sample. When focusing on the subsample of compliance traders, we cannot reject the possibility that the home bias in allowance trade is exclusively driven by the existing home bias in goods and services.

We find that the home bias differs across countries and industries, and that it decreases with firm size. This implies that transactions costs of allowance trading are heterogeneous, and as a consequence, that marginal abatement costs will not be equated across polluters in the ETS. This is important and unfortunate, since the equalization of marginal abatement costs is the main reason for efficiency gains of a cap-and-trade program relative to a uniform command-and-control regulation.

Although the econometric results are highly statistically significant and robust to a series of alternative specifications, the magnitude of the economic consequences is not clear. The welfare loss is an increasing function of the difference in (total) marginal abatement costs between the ETS firms. However, the presence of a home bias per se does not allow us to judge the magnitude of the cost differential, as even small differences in trade costs for a homogenous good can lead to an almost complete home bias. Unfortunately, prices for bilateral allowances trades are not recorded in our data. Future research (possibly based on different markets) will be needed to ascertain the welfare loss associated with the home bias documented in this paper.

Acknowledgements

Förderverein of the University of Basel for funding (Grant Nr. FV-22).

Appendix A. Appendix

Tables A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12.

Table A1
Descriptive statistics for the OHA subsample.

Variable	Sample	Mean	Std. Dev.	Min.	Max.	Obs.	Units
	Dependent Variable						
Purchases CO2 allowances	Overall	1055	43,891	0	8,008,642	350,028	tCO2
	Intensive	93,110	401,812	1	8,008,642	3967	tCO2
	Extensive	0.011	0.106	0	1	350,028	–
	Explanatory Variables						
INTRA	Overall	0.042	0.20	0	1	350,028	–
	Intensive	0.612	0.487	0	1	3967	–

Note: Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. INTRA= 1 denotes domestic transactions.

Table A2
Country-level Estimates.

Dependent Variable:	Allowance purchases		
	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)
INTRA	1.983 ***	1.976 ***	0.487 ***
	(0.184)	(0.172)	(0.011)
BC-year FE	yes	yes	yes
SC-year FE	yes	yes	yes
Obs.	6804	6804	3287

Note:'$p < 0.10$, *$p < 0.05$, **$p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For Probit estimations, the average marginal effects are reported.

Table A3
Country-specific home bias in allowance trade.

Alpha-3	Country	Home bias	Home bias cond. on trade
LUX	Luxembourg	−0.482	−2.164 **
		(0.417)	(0.465)
CYP	Cyprus	0.433	−2.668 **
		(0.604)	(1.000)
FRA	France	0.505′	−1.003 *
		(0.260)	(0.438)
GBR	United Kingdom	0.545 **	−1.192 *
		(0.157)	(0.478)
NDL	Netherlands	1.268 **	−0.036
		(0.312)	(0.483)
BGR	Bulgaria	1.457′	−1.296
		(0.756)	(1.035)
HUN	Hungary	1.501 **	−0.422
		(0.542)	(0.741)
AUT	Austria	1.511 *	−0.592
		(0.710)	(0.839)
SVK	Slovakia	1.615	−0.707
		(1.047)	(1.139)
ROU	Romania	1.962 **	−0.551
		(0.567)	(0.855)
DEU	Germany	2.679 **	1.602 **
		(0.279)	(0.365)
BEL	Belgium	2.707 **	1.409 **
		(0.163)	(0.375)
SVN	Slovenia	2.798 **	0.093
		(0.429)	(0.814)
ITA	Italy	2.900 **	1.157′
		(0.376)	(0.636)
CZE	Czech Republic	3.727 **	1.722 **
		(0.280)	(0.593)
IRL	Ireland	3.784 **	2.382 **
		(0.381)	(0.419)
NOR	Norway	3.837 **	2.060 **
		(0.624)	(0.674)
ESP	Spain	3.860 **	1.986 **
		(0.319)	(0.627)
LTU	Lithuania	4.268 **	1.425
		(0.496)	(0.896)
FIN	Finland	4.277 **	1.923 **
		(0.338)	(0.695)
GRC	Greece	4.426 **	1.680 *
		(0.323)	(0.759)
POL	Poland	4.464 **	2.550 **
		(0.455)	(0.673)
SWE	Sweden	4.793 **	2.949 **
		(0.362)	(0.600)
EST	Estonia	4.799 **	1.757 *
		(0.428)	(0.877)
POR	Portugal	5.131 **	2.640 **
		(0.462)	(0.846)
LVA	Latvia	5.295 **	2.086′
		(0.799)	(1.116)
DNK	Denmark	6.104 **	4.147 **
		(0.372)	(0.606)
Log imports in goods & services			0.369 **
			(0.095)
Observations		1,586,547	1,586,280

Note: ′$p < 0.10$, *$p < 0.05$, **$p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. All regressions include BC-year, SC-year and firm fixed effects. The first column shows the results of a regression in which we interact the INTRA dummy with individual country dummies. In the second column, we additionally control for the trade in (other) goods and services.

Table A4
sector.

	Estimate w/o interaction term	Estimate w/ interaction term
INTRA	2.673 * *	
	(0.180)	
INTRA × Digit 0		2.725 * *
		(0.505)
INTRA × Digit 1		1.909 * *
		(0.415)
INTRA × Digit 2		2.590 * *
		(0.186)
INTRA × Digit 3		3.397 * *
		(0.289)
INTRA × Digit 4		2.699 * *
		(0.696)
INTRA × Digit 5		2.176 * *
		(0.387)
INTRA × Digit 6		0.369
		(0.390)
INTRA × Digit 7		3.716 * *
		(0.401)
INTRA × Digit 8		4.132 * *
		(0.471)
INTRA × Digit 9		3.705 * *
		(0.475)
Observations	1005,473	1005,473

Note: '$p < 0.10$, * $p < 0.05$, * * $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. All regressions include BC-year, SC-year and firm fixed effects. The sector code is the first digit of the NACE rev.2 clasification; see https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC. The first digit does not correspond directly to the "main sectors" in NACE, which are denoted by letters. The null hypothesis that the home bias is equal across sectors is rejected at p < 0.001.

Table A5
Variation of home bias over time.

	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)
INTRA × 2005	2.867 * *	1.500 * *	0.061 * *
	(0.194)	(0.132)	(0.008)
INTRA × 2006	2.774 * *	1.374 * *	0.113 * *
	(0.167)	(0.103)	(0.011)
INTRA × 2007	2.881 * *	1.327 * *	0.132 * *
	(0.170)	(0.100)	(0.012)
INTRA × 2008	2.035 * *	0.802 * *	0.148 * *
	(0.300)	(0.168)	(0.115)
INTRA × 2009	1.662 * *	0.870 * *	0.097 * *
	(0.294)	(0.192)	(0.016)
INTRA × 2010	2.153 * *	0.953 * *	0.109 * *
	(0.212)	(0.109)	(0.019)
INTRA × 2011	1.785 * *	0.569 * *	0.130 * *
	(0.263)	(0.133)	(0.021)
INTRA × 2012	1.476 * *	0.597 * *	0.162 * *
	(0.256)	(0.158)	(0.024)
INTRA × 2013	1.960 * *	0.818 * *	0.243 * *
	(0.206)	(0.097)	(0.022)
Observations	1623,906	27,603	1623,906

Note: Interactions between the INTRA and country dummies. '$p < 0.10$, * $p < 0.05$, * * $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimations, the marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A6
Home bias for "Orbis sample".

Dependent Variable:	Allowance purchases					
	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	1.863**	0.814**	0.139**	0.917*	0.950**	0.017*
	(0.204)	(0.097)	(0.017)	(0.460)	(0.254)	(0.008)
Log imports in goods & services				0.226*	−0.032	0.008**
				(0.100)	(0.055)	(0.001)
Observations	1,508,567	26,209	1,508,615	1,508,615	26,209	1,508,615

Note: In these regressions, the analysis is restricted to firms that we can identify in the Orbis database. '$p < 0.10$, *$p < 0.05$, **$p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimations, the marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A7
Home bias after aggregating to the level of global ultimate owner (GUO).

Dependent Variable:	Allowance purchases					
	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	1.625**	0.724**	0.140**	0.622	0.621*	0.016′
	(0.201)	(0.110)	(0.018)	(0.462)	(0.264)	(0.009)
Log imports in goods & services				0.237*	0.024	0.008**
				(0.097)	(0.056)	(0.001)
Observations	1332,899	23,956	1332,899	1332,899	23,956	1332,899

Note: This sample is aggregated to the level of the global ultimate owner in the Orbis database. Accounts for which we found no match in Orbis, or for which Orbis supplied no GUO, are retained and treated as an individual GUO.' $p < 0.10$, *$p < 0.05$, **$p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimations, the marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A8
Home bias for the OHA subsample.

Dependent Variable:	Allowance purchases					
	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	3.521**	0.425**	0.120**	0.237	0.241	−0.001
	(0.162)	(0.130)	(0.009)	(0.514)	(0.404)	(0.002)
Log imports in goods & services				0.776**	0.047	0.008**
				(0.119)	(0.097)	(0.001)
Observations	349,712	2994	350,028	349,404	2994	350,028

Note: This sample is restricted to include only transactions of OHA accounts on the buyer as well as the seller side. $p < 0.10$, *$p < 0.05$, **$p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimations, the marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A9
Excluding France.

Dependent Variable:	Allowance purchases		
	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)
INTRA	2.146**	1.024**	0.141**
	(0.200)	(0.073)	(0.017)
Observations	1402,348	23,355	1402,348

Note: This sample is restricted to transactions where neither the buying nor the selling account is located in France.' $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For the Probit estimations, the marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A10
Home bias by market phase.

Dependent Variable:	Phase 1 only			Without phase 1		
	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	2.831**	1.395**	0.074**	1.801**	0.780**	0.164**
	(0.156)	(0.099)	(0.008)	(0.206)	(0.096)	(0.021)
Observations	458,914	3367	458,914	1,164,992	23,227	1,164,992

Note: This sample is restricted to transactions taking place during phase 1 of the EU ETS (2005–2007) (columns 1–3), or to the years without phase 1 (2008–2013).' $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For Probit estimations, the average marginal effects are reported. All regressions include BC-year, SC-year and firm fixed effects.

Table A11
Removing exchange trades.

Dependent Variable:	Allowance purchases					
	Poisson PML		Probit	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)	Overall (4)	Intensive (5)	Extensive (6)
INTRA	1.865**	0.866**	0.138**	0.819'	0.866**	0.016*
	(0.200)	(0.253)	(0.017)	(0.455)	(0.253)	(0.008)
Log in imports goods & services		−0.014		0.249*	−0.014	0.008**
		(0.054)		(0.097)	(0.054)	(0.001)
Observations	1,623,906	27,603	1,623,906	1,623,809	27,603	1,623,906

Note: In this regression, we remove all exchange trades that we can identify in the data. '$p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For Probit estimations, the average marginal effects are reported.

Table A12
Home bias based on allowance sales, 2005–2013 (full sample).

Dependent Variable:	Allowance sales		
	Poisson PML		Probit
	Overall (1)	Intensive (2)	Extensive (3)
INTRA	1.870**	0.925**	0.170**
	(0.192)	(0.115)	(0.015)
BC-year FE	Yes	Yes	Yes
SC-year FE	Yes	Yes	Yes
Account holder (Seller) FE	Yes	Yes	Yes
Observations	1,566,378	30,875	1,566,378

Note: In this regression, we aggregate the transaction data to the account holder (seller)-country (buyer)-year level (see the main text for details).' $p < 0.10$, * $p < 0.05$, ** $p < 0.01$. Standard errors (in parentheses) are clustered on the buyer-seller country pair level. Overall: All allowance purchases within the full sample. Intensive: Observations with a positive transaction volume only. Extensive: Indicator function that is 1 in case of positive trade connections, and 0 otherwise. For Probit estimations, the average marginal effects are reported.

References

Anderson, James E., Wincoop, Ericvan, 2003. Gravity with gravitas: a solution to the border puzzle. Am. Econ. Rev. 93 (1), 170–192 (March).
Anderson, James E., Wincoop, Ericvan, 2004. Trade costs. J. Econ. Lit. 42 (3), 691–751.
Atkin, David, 2013. Trade, tastes, and nutrition in India. Am. Econ. Rev. 103 (5), 1629–1663.
Auer, RaphaelA., 2017. Product heterogeneity, cross-country taste differences, and the growth of world trade. Eur. Econ. Rev. 100, 1–27.
Aviat, Antonin, Coeurdacier, Nicolas, 2007. The geography of trade in goods and asset holdings. J. Int. Econ. 71 (1), 22–51.
Beine, Michel, Bertoli, Simone, Moraga, JesúsFernández-Huertas, 2016. A PractitionersG´uide to gravity models of international migration. World Econ. 39 (4), 496–512.
Bergstrand, Jeffrey H., Larch, Mario, Yotov, Yoto V., 2015. Economic integration agreements, border effects, and distance elasticities in the gravity equation. Eur. Econ. Rev. 78 (C), 307–327.
Blum, Bernardo, Goldfarb, Avi, 2006. Does the internet defy the law of gravity? J. Int. Econ. 70 (2), 384–405.
Brülhart, Marius, Trionfetti, Federico, 2009. A test of trade theories when expenditure is home biased. Eur. Econ. Rev. 53 (7), 830–845 (October).
Chaney, Thomas, 2014. The network structure of international trade. Am. Econ. Rev. 104 (11), 3600–3634 (November).
Combes, Pierre-Philippe, Lafourcade, Miren, Mayer, Thierry, 2005. The trade-creating effects of business and social networks: evidence from France. J. Int. Econ. 66 (1), 1–29.
Correia, Sergio, Paulo Guimarães, Thomas Zylkin , 2019 , Verifying the existence of maximum likelihood estimates for generalized linear models. arXiv:1903.01633.
Correia, Sergio, Guimarães, Paulo, Zylkin, Tom, 2020. Fast Poisson estimation with high-dimensional fixed effects. Stata J. 20 (1), 95–115.
Coşar, A. Kerem, Grieco, Paul L.E., Li, Shengyu, Tintelnot, Felix, 2018. What drives home market advantage? J. Int. Econ. 110, 135–150.
Costinot, Arnaud, Rodríguez-Clare, Andrés, 2014. Handbook of International Economics, Chap. Trade Theory with Numbers: Quantifying the Consequences of Globalization. Elsevier, pp. 197–261.
Efstratios, Pourzitakis, 2012. Halting the Horses: EU Policy on the VAT Carousel Fraud in the EU Emissions Trading System. EC Tax. Rev. 21 (1), 39–51.
Ellerman, A. Denny, Trotignon, Raphael, 2009. Cross border trading and borrowing in the EU ETS. Energy J. 53–77.
Ellerman, A. Denny, Marcantonini, Claudio, Zaklan, Aleksandar, 2016. The European Union Emissions trading system: ten years and counting. Rev. Environ. Econ. Policy 10 (1), 89–107.
Evans, Carolyn L., 2003. The economic significance of national border effects. Am. Econ. Rev. 93 (4), 1291–1312.
Fabra, Natalia, Reguant, Mar, 2014. Pass-through of emissions costs in electricity markets. Am. Econ. Rev. 104 (9), 2872–2899.
Fajgelbaum, Pablo D., Khandelwal, Amit K., 2016. Measuring the unequal gains from trade. Q. J. Econ. 131 (3), 1113–1180.
Fell, Harrison, Hintermann, Beat, Vollebergh, Herman RJ, 2015. Carbon content of electricity futures in phase II of the EU ETS. Energy J. 36 (4), 61–83.
Gangadharan, Lata, 2000. Transaction costs in pollution markets: an empirical study. Land Econ. 601–614.
Green, Jessica F., Sterner, Thomas, Wagner, Gernot, 2014. A balance of bottom-up and top-down in linking climate policies. Nat. Clim. Change 4 (12), 1064–1067.
Hahn, Robert W., Hester, Gordon L., 1989. Marketable permits: lessons for theory and practice. Ecol. LQ 16, 361.
Hahn, Robert W., Stavins, Robert N., 2011. The effect of allowance allocations on cap-and-trade system performance. J. Law Econ. 54, S267–S294.
Heindl, Peter , 2012)Transaction costs and tradable permits: Empirical evidence from the EU Emissions Trading Scheme, Technical report, ZEW Discussion Paper 12–021.
Heindl, Peter and Benjamin Lutz, 2012)Carbon Management-Evidence from Case Studies of German Firms Under the EU ETS,Technical report, ZEW Discussion Paper 12–079.
Helpman, Elhanan, Melitz, Marc, Rubinstein, Yona, 2008. Estimating trade flows: trading partners and trading volumes. Q. J. Econ. 123 (2), 441–487.
Hintermann, Beat, 2016. Pass-through of CO_2 emissions costs to hourly electricity prices in Germany. J. Assoc. Environ. Resour. Econ. 3 (4), 857–891.
Hintermann, Beat, 2017. Market power in emission permit markets: theory and evidence. Environ. Resour. Econ. 66, 89–112.
Hintermann, Beat, Peterson, Sonja, Rickels, Wilfried, 2016. Price and market behavior in phase II of the EU ETS: a review of the literature. Rev. Environ. Econ. Policy 10 (1), 108–128.
Jaraitė, Jūratė, Convery, Frank, Maria, Corrado Di, 2010. Transaction costs for firms in the EU ETS: lessons from Ireland. Clim. Policy 10 (2), 190–215.
Jaraitė-Kažukauskė, Jūratė, Kažukauskas, Andrius, 2014. Do transaction costs influence firm trading behaviour in the European emissions trading system? Environ. Resour. Econ. 1–31.
Kerr, Suzi , David C.Mare , 1998 , Transaction costs and tradable permit markets: The United States lead phasedown. Available at SSRN 1082596.
Krutilla, Kerry, Krause, Rachel, et al., 2011. Transaction costs and environmental policy: an assessment framework and literature review. Int. Rev. Environ. Resour. Econ. 4 (3–4), 261–354.
Martin, Ralf, Muûls, Mirabelle, Wagner, Ulrich J., 2016. The impact of the European Union Emissions trading scheme on regulated firms: what is the evidence after ten years? Rev. Environ. Econ. Policy 10 (1), 129–148.
McCallum, John, 1995. National borders matter: Canada-U.S. regional trade patterns. Am. Econ. Rev. 85 (3), 615–623.
Melitz, Marc J., 2003. The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica 71 (6), 1695–1725.
Montero, Juan-Pablo, 1997. Marketable pollution permits with uncertainty and transaction costs. Resour. Energy Econ. 20 (1), 27–50.
Nield, Katherine, Pereira, Ricardo, 2016. Financial crimes in the European carbon markets. In: Weishaar, Stefan E. (Ed.), Research Handbook on Emissions Trading. Edward Elgar, pp. 195–231 Chap. 9.
Obstfeld, Maurice, Rogoff, Kenneth, 2001. The Six Major Puzzles in International Macroeconomics: Is There a Common Cause? NBER Macroeconomics Annual 2000, Volume 15. National Bureau of Economic Research, Inc,, pp. 339–412.
Rauch, James E., 1999. Networks versus markets in international trade. J. Int. Econ. 48 (1), 7–35 (June).
Rauch, James E., 2001. Business and social networks in international trade. J. Econ. Lit. 1177–1203.
Roux, Catherine, Santos-Pinto, Luís, Thöni, Christian, 2016. Home bias in multimarket Cournot games. Eur. Econ. Rev. 89, 361–371.
Sandoff, Anders, Schaad, Gabriela, 2009. Does EU ETS lead to emission reductions through trade? the case of the Swedish emissions trading sector participants. Energy Policy 37 (10), 3967–3977.
Santos Silva, J.M.C., Tenreyro, Silvana, 2006. The log of gravity. Rev. Econ. Stat. 88 (4), 641–658.
Spolaore, Enrico, Wacziarg, Romain, 2009. The diffusion of development. Q. J. Econ. 124 (2), 469–529.
Stavins, Robert N., 1995. Transaction costs and tradeable permits. J. Environ. Econ. Manag. 29, 133–148.
Timmer, Marcel P., Dietzenbacher, Erik, Los, Bart, Stehrer, Robert, Vries, Gaaitzen J., 2015. An illustrated user guide to the world input-output database: the case of global automotive production. Rev. Int. Econ. 23 (3), 575–605.
Wolf, Holger C., 2000. Intranational home bias in trade. Rev. Econ. Stat. 82 (4), 555–563.
World Bank, 2012. State and Trends of the Carbon Market 2012. Carbon Finance at the World Bank.
Zaklan, Aleksandar , 2013 , Why Do Emitters Trade Carbon Permits?: Firm-Level Evidence from the European Emission Trading Scheme. Discussion Papers of DIW Berlin 1275, DIW Berlin, German Institute for Economic Research.