Is industrial decarbonization at odds with competitiveness? An assessment of competition dynamics in two EU heavy industries

Working paper - do not diffuse

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Abstract

Defining a fair and transparent measure of carbon leakage risk is primordial to effectively tackle carbon leakage without undercutting the impact of climate policies. An essential factor to achieve this is understanding the market structure of the sectors that are evaluated. This paper proposes a new approach to analyze this market structure, and applies it to the EU's steel and cement industries. The micro-founded hypothetical monopolist test (or SSNIP) is applied at a country-product level to delineate the relevant market for both industries. A gravity model is used to estimate technical substitution elasticities at the product level, from which own- and cross-price elasticities are derived. The latter are then used as inputs in the hypothetical monopolist test. The results from this analysis point to steel markets being delimited at a strictly national level, while the relevant market for cement seems to include several countries, including some outside of the EU for clinker.

Keywords: climate policies, hypothetical monopolist, gravity model, carbon leakage, carbon border adjustment

JEL Codes: H23, L51, O33, Q58

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1 Introduction

The EU's industrial sector makes up roughly 22% of its total greenhouse gas (GHG) emissions (EEA, 2022). To stay in line with its objective of carbon neutrality by 2050, these industrial emissions must be rapidly and significantly cut down. While ambitious and effective climate policies are necessary to create a framework that incentivizes firms to invest in the decarbonization of their production processes, policymakers are wary of the risk of carbon leakage if these policies are implemented unilaterally. Indeed, policies must strike a difficult balance between constraining firms enough to reach climate objectives and not overburdening them so much that they lose out to unregulated competitors or decide to relocate their production.

In the EU, the central policy for the decarbonization of the industrial sector is the EU Emission Trading Scheme (ETS). This scheme places an increasingly binding cap on the total emissions of covered firms, and allows these firms to buy and sell emission quotas. This creates an incentive for them to abate their emissions to avoid paying for quotas that become more and more expensive as the cap is lowered.

In an effort to avoid generating carbon leakage when implementing the EU ETS, policymakers coupled the scheme with carbon leakage mitigation measures. These took the form of free allocations and indirect cost compensation to all sectors in the first two phases of the EU ETS, then only to the sectors considered to be at significant risk of carbon leakage starting from the third phase onward.

With some time having passed since their first implementation, free allocations have been criticized for being too generous and muting the EU ETS' incentivizing effect. Evidence shows that some sectors subject to the EU ETS – including those that received free allocations – actually have a strong capacity to pass their costs through to final consumers, and that they exercised this power for ETS-related costs (Cludius et al., 2020). Additionally, and contrary to what is stated in economic theory, using free allocations instead of auctioning seems to have had a non-neutral effect on firms' abatement decisions, with free allocations inducing less emissions reductions than auctioning (De Vivo & Marin, 2018). There appears to have been a mismatch between the leakage risk projected by policymakers when designing leakage mitigation measures and the actual leakage risk that industrial sectors faced as a result of the implementation of the EU ETS.

At the core of these considerations is the issue of defining a fair and transparent measure of carbon leakage risk. This measure is essential to design leakage mitigation measures that effectively tackle the problem *without* undercutting the impact of climate policies

(Cosbey et al., 2019). It is what allows policymakers to determine which sectors or products need to be covered, and how much protection they actually need.

Defining this measure is a difficult task for two main reasons. First, carbon leakage has never been empirically observed because no climate policy in the world has yet been stringent enough to generate this effect (Cameron & Baudry, 2022; Verde, 2020). This makes it difficult to apprehend the magnitude of the impact a particular policy or carbon price level can have on firms. Second, the choice of a carbon leakage measure itself is extremely contentious, because it determines which sectors receive free allocations - which can be a source of large rents for firms with strong pass-through (Sato et al., 2015). As a result, competitiveness and carbon leakage concerns are often raised by industry trade associations to lobby the EU on its climate policies (Fagan-Watson et al., 2015).

A large strand of economic literature has attempted to measure the risk of carbon leakage in various policy contexts. Theoretical approaches using game theory were first developed in the 1990s (Hoel, 1991; Markusen et al., 1993) to explain the mechanisms underlying carbon leakage. These models were then applied to Computable General Equilibrium models simulating the impact of stringent policies on a variety of parameters. These models have found variable, but generally low, leakage rates[1]. Empirical papers have also attempted to quantify carbon leakage induced by existing climate policies, but overall have found almost no effect - likely because climate policies have not been stringent enough to induce this kind of an effect[2].

On the policy side, the EU measures the risk of carbon leakage by applying a criterion which is based on sectors' trade intensity and energy intensity. Trade intensity is used as a proxy to measure how much international competition a sector faces, which itself is used as an indication of its ability for cost pass-through. Energy intensity is used as a proxy of the compliance cost imposed by the EU ETS on firms. This criteria is fairly rudimentary, and is not based on any strong economic justification.

Some literature has focused on assessing the EU's methodology and proposing alternative criteria to measure carbon leakage risk. Overall, this strand of research tends to show that the EU's measure of carbon leakage may be overstating risks because it aggregates sectors too much (Fischer & Fox, 2018), omits any country-level differences in exposure (Sato et al., 2015) and does not account for non-price trade barriers such as integrated production processes, service specification, or resource base locations (Hourcade et al., 2007). Addition-

[1]See Branger and Quirion (2014) and Carbone and Rivers (2017) for a review of the literature on this topic.

[2]See Joltreau and Sommerfeld (2019) and Verde (2020) for a review of the literature on this topic.

ally, the EU's measure does not consider whether there is any form of market power in the sectors that are considered, although evidence points to some existing (Cludius et al., 2020).

Fischer and Fox (2018) provide econometric estimates of parameters related to trade sensitivity and compare them to parameters used by policymakers to measure leakage risk. Fowlie and Reguant (2018) discuss a simple model of carbon leakage to highlight the challenges associated with its measure and identify key areas for future research. They specifically note that modeling foreign output responses to unilateral climate policies could be improved. Sato et al. (2015) compare carbon leakage measures used by policymakers with measures derived from industry consultations. Martin et al. (2014) also perform industry consultations, which they combine with firm-level economic data. They find that most EU ETS sectors were likely overcompensated due to an overestimation of carbon leakage risk, but that there was significant variability in the vulnerability of different firms.

This paper aims to contribute to this literature assessing carbon leakage risk by proposing a new approach: the application of the hypothetical monopolist test - also known as the SSNIP[3]test (Werden, 2003) - on a country-product level. This approach is applied to the steel and cement sectors. The parameters used in this test are derived from gravity model estimates of the CES substitution elasticity. Both of these methods are anchored in a monopolistic competition framework and can therefore be linked both theoretically and empirically. Additionally, the estimation of substitution elasticities at a product level for two industrial sectors contributes to the international trade literature on Armington elasticities (Armington, 1969).

This approach has several advantages compared to other existing methods. First, it allows for a highly-disaggregated sectoral analysis, even allowing for theoretically consistent product-level results. Second, it simultaneously takes into account the impact of trade elasticities, like CGE models, and market power dynamics - an element which has been omitted in most approaches so far but is found to be of importance in ex-post empirical evaluations of EU ETS sectors.

Section 2 provides some contextual information on the sectors this paper focuses on, and especially on their characteristics related to trade and carbon intensity. Section 3 presents the theoretical linking between the hypothetical monopolist test and the gravity equation, as well as the empirical strategy that is used for the estimation of the latter. Section 4 describes and provides sources for the data that is used in this paper. Finally, section 5 presents the results of this analysis and section 6 concludes.

[3]Small but Significant Non-Transitory Increase in Price

2 Industrial context

Cement. The cement manufacturing process begins with the mining and grinding of raw mineral materials, mostly limestone and clay. The resulting powder is heated to 1450° which breaks down and recombines its chemical bonds to create a new compound: clinker. Clinker are nodules that can go from 1 to 25mm in diameter. These are ground into powder to create cement, to which water and other minerals are added to create concrete. Concrete is the material that is used in construction. The most commonly used type of cement is hydraulic cement, defined by its ability to set and harden through a chemical reaction with water. In this paper, clinker and hydraulic cement are the products that are studied for the cement industry.

Two-thirds of GHG emissions in cement manufacturing are process emissions caused by the chemical reaction used to produce clinker (Mari et al., 2021). The remaining third originate from energy use. Cement production makes up roughly 3% of total GHG emissions in the EU (Emele et al., 2022). It is also the most carbon intensive industrial sector (see figure 2).

China is by far the largest producer of hydraulic cement and clinker, followed by India, the USA and Brazil. Appendix 1.2 provides graphs of production quantities for hydraulic cement by country. Due to its high transport costs, most cement is produced and consumed domestically, meaning the sector is not very trade intensive (see figure 1 and figure 2).

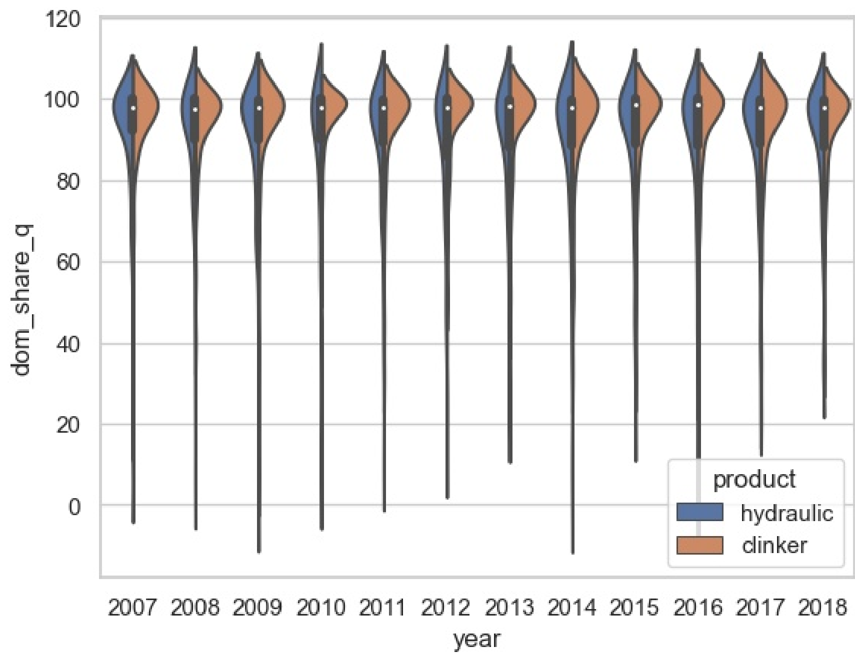

Figure 1: Percentage of own-production of cement consumed domestically
Source: Author based on Gaulier and Zignago (2010), Curry (2018) and van Oss (2008, 2013) and GCCA.

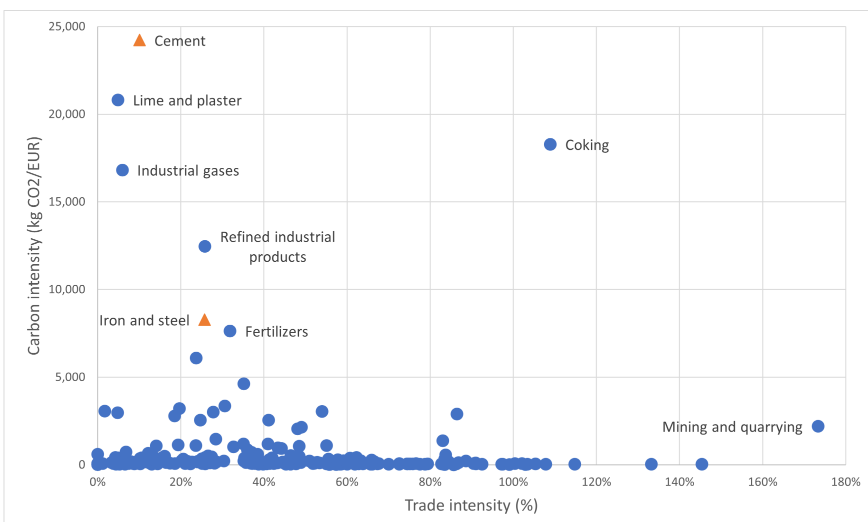

Figure 2: European Commission carbon leakage indicators
Source: Author based on European Commission data[4]

[4]This data can be shared by the author upon request by email.

Steel. The steelmaking process consists in smelting iron ore into steel, adding or removing certain elements and finally casting the steel into different shapes. There is a distinction between flat steel products, which are generally used in car manufacturing and household appliances, and long steel products, which are generally used in infrastructure. Importantly, these two different types of products do not have the same requirements in terms of the quality of inputs used to make them, and are therefore produced in broadly different ways. Flat products are generally produced in blast furnaces, which are highly carbon intensive, while long products can be produced in electric-arc furnaces. This might mean these products are not equally sensitive to carbon pricing schemes.

Once again, China is unquestionably the largest producer in the world of both products (see Appendix 1.2). The USA and Japan are the world's second and third largest producers of flat steel products, while India and Japan are for long steel products. Steel products are traded more than cement (figure 3), especially flat steel products, but are less carbon intensive (figure 2). Relative to other industrial sectors however, they are still highly carbon intensive.

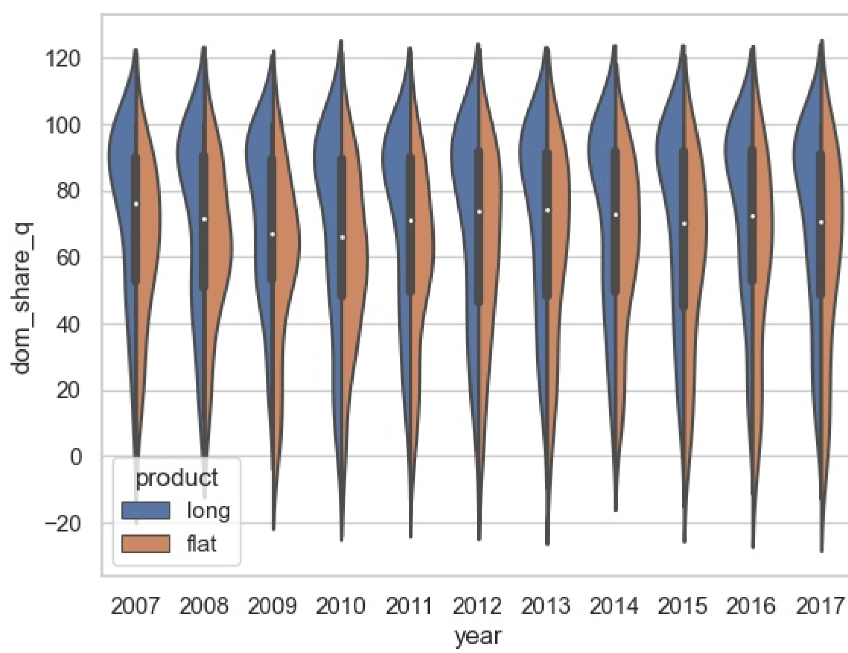

Figure 3: Percentage of own-production of steel consumed domestically
Source: Author based on Gaulier and Zignago (2010) and World Steel Association (2016; 2018).

3 Model

The model is split into two parts, both of which are anchored in a monopolistic competition framework. There are N countries in the world. There are $2 \times N$ agents in this model: an upstream producer and a downstream producer in each country. The upstream producers use labor and raw materials (such as lime or iron ore) to produce industrial goods (such as cement or steel). The downstream producers buy industrial goods from the upstream producer and uses them as inputs, with labor, to produce final goods (such as construction materials or cars). An Armington (1969) structure of international trade for the industrial good (hereafter the good) is assumed, meaning varieties of the good are differentiated by country of origin and each country only produces one variety. In this set-up, indexing by upstream producer, country or good is strictly equivalent.

The first part of the model is the hypothetical monopolist test - or SSNIP test (Werden, 2003). This test was developed in competition economics and is generally used at the firm level. Here, it is applied at the meso (country-product) level. The test delineates the relevant market an upstream producer operates on based on information on its margin rates and profit, and on a downstream producer's own- and cross-price elasticities. While it is possible to find data on margin rates and profit at the country-product level, own- and cross-price elasticities must be estimated. Elasticities are derived from the second part of the model, a modified gravity model (Yotov et al., 2016) applied at the product level. The main characteristics of each part of the model are described hereafter, while a full derivation can be found in Appendix 2.

3.1 Part one: the Hypothetical Monopolist Test

The hypothetical monopolist test is an iterative method that delineates the relevant market for one particular product and baseline country. It is based on the idea that a hypothetical monopolist could theoretically exercise market power on said relevant market without losing out to competitors outside of the market - meaning there are no adequate substitutes outside of this market.

Taking a country j as a starting point, the test posits that there is a hypothetical monopolist which controls the production of good j and of its substitutes $i \in \Theta_j = \{1, ..., N'\}$ with $i \neq j$ and $\Theta_j \subset \{1, ..., N\}$. It then checks whether this hypothetical monopolist could impose some form of market power on j and substitutes Θ_j. If the test returns a negative result, then an additional substitute $N'+1$ is added to the hypothetical monopolist grouping and the test is run again. If the result is positive, the test is stopped and the relevant market is composed of j and Θ_j.

Formally, the test determines whether it is *profitable* for the hypothetical monopolist to increase the price of j by a small but significant amount, set by convention at $+5\%$[5]of the observed price. The observed price is presumed to be the result of a competitive equilibrium. Essentially, this means testing whether profits made by a hypothetical monopolist controlling the production of j and its substitutes $i \in \Theta_j = \{1, ..., N'\}$ are greater after this monopolist increases the price of j by 5% (post-increase) than in the initially observed situation (pre-increase). Indeed, by calculating profits made on product j after the price increase, the test captures the price effect of this price increase, while it captures a substitution effect by also including the profit made on substitutes Θ_j. This substitution effect can also be understood as a form of leakage, given that it is the amount of consumption that is transferred to another country after a price increase in j. The condition is written as below for this test:

$$\Pi^{post}_{j+\Theta_j} > \Pi^{pre}_{j+\Theta_j} \tag{1}$$

$$\Leftrightarrow \Delta\Pi_{j+\Theta_j} > 0 \tag{2}$$

This is equivalent to testing for the following condition (see Appendix 2.1 for a full derivation of this result):

$$-\varepsilon_{jj} < \frac{1}{\mu_j + x} + \sum_{i \neq j}^{N'} \frac{\mu_i}{\mu_j + x} \frac{v_i}{v_j} \varepsilon_{ji} \tag{3}$$

Where ε_{jj} is country j's own-price elasticity, ε_{ji} is country j's cross-price elasticity with the product from country i, and the term on the right hand of the inequality is the critical elasticity for the hypothetical monopolist test; μ and v are the margin rates and turnover, respectively. If condition 3 is verified, then it is profitable for the hypothetical monopolist to impose a price increase on product j, meaning there are no substitutes outside the market. The relevant market for baseline country j is defined at this point.

[5]The threshold of 5% is standard in the literature as it is considered a small but significant price increase.

3.2 Part two: Gravity model

Gravity model. This paper uses a modified version of the standard gravity model based on micro-founded monopolistic competition (Yotov et al., 2016). It is modified in that the optimizing agent is a downstream producer buying industrial goods from an upstream producer rather than a consumer buying consumption goods from a producer, as is usually the case. The downstream producer has a nested CES production function. For a given country $j \in \{1, ..., N\}$ importing from all other countries, the top level of this production function, specifying the substitution between labor and the aggregate industrial good, is defined as:

$$Y_j = L_j^{\alpha} M_j^{1-\alpha} \tag{4}$$

Where L is labor and M is the aggregate industrial good. The aggregate industrial good has N different varieties, one for each country/upstream producer in the world. The downstream producer's sub-production function for these different varieties is defined by the following CES function:

$$M_j \equiv \left(\sum_{i=1}^{N} m_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad ; \ \sigma > 1 \tag{5}$$

Where σ is the CES elasticity of substitution between different varieties of the industrial good, m_{ij} is the quantity used in physical units of each variety and $i \in \{1, ..., N\}$ is the exporting country. Setting $\sigma > 1$ implies that varieties of the industrial good are substitutes rather than complements. Downstream producers therefore do not necessarily need to consume all varieties of the industrial good for their production, but could theoretically consume even just one variety. In fact, if a market is purely national, the downstream producer could consume only the variety from the domestic upstream producer.

Solving for the downstream producer's cost minimization problem, the demand for each variety is expressed as (see Appendix 2.2 for the full derivation of this result):

$$m_{ij}^{*} = p_{ij}^{-\sigma} M_j^{*} \left(\sum_{i=1}^{N} p_{ij}^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \tag{6}$$

Where M_j^* is the optimal quantity consumed of the aggregate industrial good in country j and p_{ij} is the price of the variety from country i sold in country j. This price is defined as $p_{ij} = p_i t_{ij}$ where p_i is the factory-gate price in country i and t_{ij} are transport costs from country i to country j.

As shown in Appendix 2.2, the trade flow in monetary units X_{ij} of the industrial good exported from country i to country j can be expressed as:

$$X_{ij} = \frac{(p_i t_{ij})^{1-\sigma}}{P_j^{-\sigma}} M_j^* \tag{7}$$

Where P_j is the price index in country j. The market clearing condition is that production of the good in country i, O_i, is equal to the sum of its exports to all countries ($j \neq i$), including itself - i.e., domestic sales, also known as intra-national trade ($j = i$):

$$O_i = \sum_{j=1}^{N} \frac{(p_i t_{ij})^{1-\sigma}}{P_j^{-\sigma}} M_j^* \tag{8}$$

Given that there are no reliable sources of transport cost data for international trade, especially at the product level, trade economists generally use a set of related indicators to proxy for transport costs. A large strand of literature has focused on identifying the determinants of trade costs, a subset of which are now considered as standard proxies and are known as gravity distance variables. The most significant of these is a measure of geographical distance between two trading partners. Even in recent years, a very robust and positive relationship exists between the distance and the transport costs between any two countries. A set of "cultural distance" indicators can also modify transport costs by impacting administrative or regulatory costs for trading partners. The most commonly used cultural distance indicators are contiguity, a common official language between two countries, former colonial ties, and the participation in a common regional trade agreement (Yotov et al., 2016). Following this literature, transport costs are defined as in equation 9 below, with δ_j importer j's distance coefficient, $dist_{ij}$ the geographical distance between countries i and j and D_{ij} a vector of the standard cultural distance variables.

$$t_{ij} = \delta_j dist_{ij} \exp(\theta_j D_{ij}) \tag{9}$$

From this framework, the gravity equation that is used for estimation is derived. A PPML estimator with importer-year $\varphi_{i,t}$ and exporter-year $\chi_{j,t}$ fixed effects is used. Appendix 2.2 details the steps to reach this expression of the gravity equation:

$$\log X_{ij,t} = -\log O_t + (1-\sigma)\log dist_{ij,t} + D_{ij} + \pi_{i,t} + \chi_{j,t} + \epsilon_{ij,t} \tag{10}$$

Own- and cross-price elasticities. We derive expressions of country j's own- and cross-price elasticities from the same monopolistic competition framework. These elasticities are dependent on the CES substitution elasticity between varieties σ, the Cobb-Douglas parameter for the industrial good α and prices of the different varieties:

$$\varepsilon_{jj} = (-\sigma) + (\sigma - \alpha)\frac{p_{jj}^{1-\sigma}}{\sum_{i=1}^{N} p_{ij}^{1-\sigma}} \tag{11}$$

$$\varepsilon_{ij} = (\sigma - \alpha)\frac{p_{jj}^{1-\sigma}}{\sum_{i=1}^{N} p_{ij}^{1-\sigma}} \tag{12}$$

4 Data

As discussed in the previous section, the model is split into two parts. The first part is the hypothetical monopolist test, which is run using results from the second part, a product-level gravity model. The data used in the gravity model, as well as its pre-treatment are described in a first sub-section. The second sub-section turns to the inputs and data used in the hypothetical monopolist test.

4.1 Gravity model data

4.1.1 International trade data

The main source of data used for the gravity model is CEPII's BACI dataset[6] (Gaulier & Zignago, 2010). It contains data on quantities and values of international bilateral trade flows for 150 countries between 1995 and 2020. The HS07 version of this dataset[7]is used. This version was last updated in February 2022, and spans from 2007 to 2020.

[6]Available at the following URL:
http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37

[7]The Harmonized System (HS) is a nomenclature for traded products which is internationally standardized. It was developed and is maintained by the World Customs Organization. The HS is updated every few years, generally with added granularity in the nomenclature. Using the 2007 version provides sufficient granularity to perform a highly disaggregated analysis, but it also reduces the sample size since data for this version of the nomenclature only goes back to 2007.

CEPII's BACI database is drawn from COMTRADE tariff data. While the creators of BACI treat the raw COMTRADE data to have more reliable unit values[8], there are still some variations in unit values which seem implausible and are likely caused by misreporting in the original data. Tariff data can be unreliable in some cases due to insufficient monitoring from customs administrations and other issues (Yotov et al., 2016). To overcome this issue, a procedure is implemented to detect outliers in unit values (defined as the ratio between the value of a trade flow and its quantity). Following Berthou and Emlinger (2011) who use a similar procedure on the United Nations Statistical Division's "Tariff Lines" database, the procedure aims to capture outliers based on two dimensions: temporal and geographical.

Outliers are identified according to the following criteria:

- Unit values that are 100 times greater or 100 times smaller than the median unit value for each product-importer-exporter grouping;
- Unit values that are 100 times greater or 100 times smaller than the median unit value for each product-importer or product-exporter grouping;
- Unit values that are 1000 times greater or smaller than the value of the immediately preceding or following year.
- Unit values for which the quantity is less than 0.1 ton (these are generally very close to 0 and seemingly included as placeholders rather than real values).

This method identifies roughly 10% of outliers in cement trade flows and 12% in steel trade flows. However, these are generally very small trade flows, which make up 0.48% and 0.39% of quantities traded for cement and steel respectively.

For each of the flagged trade flows, the quantity is dropped and replaced by the value of the flow divided by the median unit value for each product-importer-exporter grouping (or each product-importer or product-exporter grouping if the product-importer-exporter median value is not available).

Finally, the dataset is aggregated to a product level, as outlined in Appendix 1.1. In the final database, cement is classified as either clinker or portland cement and steel products are split into flat or long products.

[8]Unit values are defined as the value of an trade flow divided by its quantity.

4.1.2 Intra-national trade data

To be theoretically consistent, gravity models require intra-national trade data. Intra-national trade represents the volume of goods that a country both produces and consumes domestically. While most countries do not report direct measures of intra-national trade[9], a common way to measure this variable is to take the difference between a country's gross production of a good and the sum of all exports of that good from the same country to other countries (Yotov et al., 2016).

Some databases use this method to provide intra-national trade data at a relatively aggregated level - generally at the 2- or 3-digit level of the Industrial Standard Industrial Classification (ISIC) Rev. 3[10]. At the 3-digit level, there are sectors such as "Iron and steel" or "Other non-metallic mineral products". In this paper, more disaggregated production data is used to calculate intra-national trade volumes, thus avoiding - or at least minimizing - the aggregation bias which has been noted in the gravity literature (Anderson & van Wincoop, 2004; Anderson & Yotov, 2010).

For flat and long iron and steel products, data from the World Steel Association's Statistical Yearbooks[11]is used. Specifically, the 2016 and 2018 editions of the Yearbook (World Steel Association, 2016; 2018) where digitized. These yearbooks provide data on the gross production of flat (table 13 in the Yearbook) and long (table 12 in the Yearbook) steel products by country from 2006 to 2017 in thousand metric tons.

For hydraulic cement products, data from the United State's Geological Survey's Cement Statistics and Information[12]is used - namely tables 22/23 of the 2008, 2013 and 2018 editions of the Minerals Yearbook (van Oss, 2008; 2013; Curry, 2018). These tables provide data on the production of hydraulic cement by country between 2004 and 2017 in thousand metric tons.

To the best of my knowledge, comprehensive clinker production data is not readily available. The Global Cement and Concrete Association (GCCA) provides this type of data for a selected number of countries, but not for the full sample the rest of our data covers[13].

[9]Canada is a notable exception to this. The Government of Canada provides data on trade between provinces which has been used in some of the foundational studies in gravity economics (see McCallum (1995) for example). However, this data does not include intra-provincial trade, i.e., the value of goods that are both produced and consumed directly within a province.

[10]See for instance the World Bank's Trade, Production, and Protection Database, the CEPII's TradeProd database, or the United Nations Industrial Development Organization's INDSTAT database.

[11]Available at the following URL:
https://worldsteel.org/steel-topics/statistics/steel-statistical-yearbook/.

[12]Available at the following URL:
https://www.usgs.gov/centers/national-minerals-information-center/cement-statistics-and-information

To work around this, estimates of clinker production volumes are calculated as the product of hydraulic cement production volumes and a region's clinker-to-cement ratio, to which clinker exports are added and clinker imports removed. A comparison of this proxy to the GCCA's data for available countries shows that it performs relatively well for most countries, with some notable exceptions including Egypt, India and Thailand. Appendix 1.4 provides graphs comparing the constructed clinker production data with the GCCA's data.

This production data was merged with the previously described international trade data from BACI to generate intra-national trade flow volumes, using the product classification crosswalk described in Appendix 1.1. Appendix 1.2 provides graphical representations of the production data presented in this section.

4.2 Hypothetical monopolist test data

4.2.1 Own- and cross-price elasticities

As illustrated in equations 11 and 12, own- and cross-price elasticities are calculated based on three elements: the CES elasticity of substitution between varieties of a good σ, the Cobb-Douglas parameter α, and prices for each variety. We detail the source of data for each of these elements here.

CES elasticity of substitution. Product-specific CES elasticities of substitution σ are derived from the estimated gravity model. σ is defined as 1 minus the coefficient associated with the log distance variable.

Cobb-Douglas alpha parameter. The α parameter is derived from the University of Groeningen's WIOD input-output database[14]. It is calculated as the share of cement or steel consumed by all branches of a country's economy in that country's total costs - which is equated to total production.

[13]The GCCA database provides clinker production data for the following countries and regions: World, Africa, Asia (n.e.c.) + Oceania, Austria, Brazil, Canada, Cembureau members, Central America, China + Korea + Japan, CIS, the Czech Republic, Egypt, EU 28, Europe, France, Germany, India, Italy, Latin America, the Middle East, Morocco + Algeria + Tunisia, North America, the Philippines, Poland, South America ex. Brazil, Spain, Thailand, the United Kingdom, and the United States.

[14]Available at the following URL:
https://www.usgs.gov/centers/national-minerals-information-center/cement-statistics-and-information

Pricing data. While pricing data is difficult to access directly due to its highly sensitive nature, a proxy value is calculated based on the available trade data. Domestic prices for a country are estimated as the quantity weighted average of this country's export prices.

While it may not perfectly reflect the real domestic prices of the products we study, this proxy was checked against some steel pricing data made available by the OECD for specific countries. The proxy was found to roughly match the evolution of the OECD's data (see Appendix 1.3 for graphs comparing the constructed data with the OECD's data). A correlation of 71% and 51% was found between the two datasets for flat and long products respectively. Concerning cement, to the best of my knowledge there is no reliable data on domestic pricing which could be used to compare with the constructed data.

4.2.2 Turnover and gross operating surplus

Finally, the hypothetical monopolist test requires data on turnover and margin rates for each country included in the test. While it is difficult to recover complete data on margin rates due to its sensitive nature, Eurostat provides values for some countries and industrial sectors in the EU, for selected years. I use this data as a base, and use the mean value of all margin rates for countries where data is not available.

The data used from Eurostat is the [sbs_a_ind_r2] series from their Structural Business Statistics series. Specifically, the "Gross operating rate - percentage" indicator from this series is used.

Turnover is calculated by multiplying the production data presented in section 4.1.2. with unit values presented in section 4.1.3.

5 Results

5.1 Estimation of elasticity of substitution

The first step to implement this paper's model is the estimation of a gravity equation for each of the four products that are studied. I estimate equation 10 using a PPML estimator, as recommended in the literature (Yotov et al., 2016). The results from these estimations are presented in table 1 below. The coefficient for log distance, our variable of interest, is negative and significant for all four products. This is in line with expectations that the further apart two countries are from each other, the less they will trade with each other.

Given the value of the log distance coefficient, each product's elasticity of substitution can be calculated. This elasticity is defined as 1 minus the log distance coefficient. Values for the substitution elasticity σ are shown in table 2. Overall, substitution elasticities are found to be between 3 and 4.

Table 1: PPML gravity model

	Dependent variable:			
	Trade flow			
	(1)	(2)	(3)	(4)
	Hydraulic cement	Clinker	Flat steel products	Long steel products
Log distance	-3.422***	-3.577***	-2.043***	-2.598***
	(0.070)	(0.120)	(0.047)	(0.069)
Contiguity	-0.952***	-1.997***	-0.673***	-0.631***
	(0.143)	(0.268)	(0.167)	(0.174)
Common language	-0.765***	-0.835***	-1.379***	-0.855***
	(0.253)	(0.327)	(0.319)	(0.370)
Colonial ties	0.285	0.238	1.241***	0.165
	(0.324)	(0.515)	(0.218)	(0.354)
Regional trade agreement	-1.869***	-3.054***	-0.410***	-0.629***
	(0.122)	(0.229)	(0.125)	(0.156)
Observations	9832	2873	4351	8166
AIC	114154128.879	34390330.803	679392298.919	499089363.947
BIC	114011723.179	34351364.664	679314921.38	498952449.049
Likelihood	-57075993.44	-17194360.402	-339695840.459	-249544158.974

Note: *p<0.1; **p<0.05; ***p<0.01

Table 2: Elasticity of substitution σ

Product	σ
Hydraulic cement	4.421^{***} (0.070)
Clinker	4.577^{***} (0.120)
Long	3.598^{***} (0.069)
Flat	3.043^{***} (0.047)

Note:
*p<0.1; **p<0.05; ***p<0.01

5.2 Own- and cross-price elasticities

Own- and cross-price elasticities are calculated as defined in equations 11 and 12. Table 3 reports the own-price elasticities for all countries in the data. For each country and product, data from the most recent year available is taken to calculate this elasticity.

It should be noted that as the number of countries included in the hypothetical monopolist test increases with each iteration that is run, the value of the own-price elasticity will decrease. This is because the denominator in the price ratio part of the elasticity's definition increases with the number of countries included, which drives the value of the entire equation down. Intuitively, this can be interpreted as the fact that as more and more varieties are included in the hypothetical monopolist grouping, there are less and less varieties outside of the grouping that producers can substitute their consumption towards. This makes it increasingly likely that the hypothetical monopolist will return a positive result as more countries are included in the grouping.

Cross-price elasticities are also derived for all countries. The same observation as with the own-price elasticity can be made here. As the number of countries included in the test increases, the value of the cross-price elasticity will also decrease, given that the denominator of the price ratio term of the formula will increase. This will have the effect of also decreasing the value of the critical elasticity.

Table 3: Own-price elasticities by country and product (latest available year of data)

country	**clinker**	**flat**	**hydraulic**	**long**
AUS	-7.72398	-3.84155	-0.46518	-9.39003
AUT	-8.10898	-6.28505	-5.04302	-4.37974
BEL	-5.23284	-2.81728	-5.01203	
BGR	-14.2618	-1.49351	-6.0801	-4.45267
BRA	-0.00095	-3.45466	-4.10429	-9.40446
CAN	-11.0213	-1.91681	-8.76299	-9.39594
CHE	-0.79607		-11.3005	
CHN	-2.76708		-1.45569	-9.57233
CYP	-2.54045		-3.26306	
CZE	-1.88145	-3.58095	-8.71323	-9.42988
DEU	-8.30985	-6.27714	-10.8579	-9.41489
DNK	-5.66204		-4.22345	
ESP	-12.7406	-6.27565	-2.38873	-9.41313
EST	-6.73307		-15.0383	
FIN	-0.12403	-6.26373	-0.67424	-1.48296
FRA	-9.64694	-6.24765	-0.97347	-9.38004
GBR	-1.03414	-2.49108	-0.38593	-3.54677
GRC	-14.5681		-12.862	-9.39038
HRV	-12.1379		-1.67239	-9.39294
HUN	-4.23902	-3.876	-2.82989	-3.81304
IDN	-7.81413	-2.0199	-15.1549	-9.40027
IND	-3.58964		-6.14408	-9.53301
IRL	-7.12912		-6.0571	
ITA	-8.51074	-6.27572	-14.8059	-6.17689
JPN	-5.56202		-15.1585	-9.47811
KOR	-15.8306		-4.73681	-9.52975
LTU	-1.39687		-8.32308	
LUX	-5.67954		-10.8813	-9.37749
LVA	-16.4184		-6.49826	-9.38171
MEX	-16.3552	-0.91131	-15.0636	-9.41381
NLD	-0.68172	-3.30304	-1.44837	
NOR	-1.8E-06		-11.0788	-5.99497
POL	-2.5143	-3.61162	-0.43233	-4.293
PRT	-16.417		-14.092	-6.38249
ROU	-1.48768	-6.2869	-2.28163	-9.42644
RUS	-7.28328	-3.47566	-4.41773	-9.47617
SVK	-9.19558	-6.2731	-8.43001	
SVN	-2.73549	-0.90588	-7.53897	-2.60286
SWE	-16.3953	-6.26606	-8.45702	-9.40179
TUR	-0.84192		-14.7238	-9.42881
USA	-2.64375		-4.19979	-9.38363

5.3 Implementation of the hypothetical monopolist test

To begin, I have run this test taking France as the baseline country. This means I am delineating the relevant market for France's producers, running the test separately for each product. In its first iteration, the test considers the case where the hypothetical monopolist is made up only of the country for which we want to delineate the relevant market. If the hypothetical monopolist test returns a positive result in this first iteration, this can be interpreted as the relevant market being purely national. If it returns a positive result after several iterations, the countries that have been included in these iterations have to be included in the relevant market.

Table 4 provides the results for France's clinker, hydraulic cement, flat and long steel production. The test is run for all years of available data. The relevant market for flat and long steel products is noticeably stopped at the national level in this case. Looking further into these results uncovers the fact that the critical elasticities for this first iteration of the test are uncharacteristically large. The size of these critical elasticities is largely driven by the first term in the formula to calculate them, i.e., the inverse of the margin rate plus the price increase. In the data we take from Eurostat, margin rates are relatively low for steel products, with mean values for all countries going from -5% to 2% for flat steel products and from -2% to 8% for long steel products. This makes this first term quite large to begin with and inflates the value of the critical elasticity for these products.

One explanation for this can be that the margin rates observed in this data are those based on real market conditions. Therefore, if the market is already quite competitive, then margin rates will be low. As a result, when I take existing competitive margin rates and input them in the calculation of a critical elasticity in a hypothetical world where the market is only one country, a problem arises. Similarly to the well-known case of the cellophane fallacy, there is a bias in the calculation of the critical elasticity because one of the parameters that is included in this calculation is actually dependent on pre-existing market conditions which the critical elasticity is trying to measure. To measure this bias, further research could compare observed margin rate values with margin rates derived from a counterfactual analysis where no competition is observed.

For clinker and hydraulic cement, the case is slightly different. The relevant market for hydraulic cement is generally found to be between Belgium and France, with Germany included in 2013, and Spain in 2014 and 2015. Margin rates are a lot higher for this industry, with mean values around 20% for all years. This drives the critical elasticity down quite significantly which can explain why the market delineation goes beyond the national market.

This result is relatively in line with other works showing that hydraulic cement is difficult to trade across long distances and is generally traded amongst neighboring countries.

Finally, the results for clinker seem to show that the relevant market also goes beyond national borders. However, the countries that are included in the relevant market are less stable across the years than for clinker, and are much further away geographically. This could indicate a greater ease of transport for clinker.

While these results need to be further analyzed and explained, a preliminary interpretation could be that the relevant market for these products, taking France as a baseline country, is quite restricted. This could indicate some form of market power in these industries. It could also be interpreted as the fact that French producers are able to differentiate their products enough that they do not compete directly with producers from other countries.

Table 4: Market delineation results for France as the baseline country

Year	**clinker**	**flat**	**hydraulic**	**long**
2007	THA, FRA	FRA	BEL, FRA	FRA
2008	VEN, FRA	FRA	BEL, FRA	FRA
2009	COL, FRA		BEL, FRA	FRA
2010	VEN, FRA	FRA	BEL, FRA	FRA
2011	VEN, FRA	FRA	BEL, FRA	FRA
2012	VEN, FRA	FRA	BEL, FRA	FRA
2013	COL, FRA	FRA	DEU, FRA	FRA
2014	COL, FRA	FRA	FRA, ESP	FRA
2015	COL, FRA	FRA	FRA, ESP	FRA
2016	VNM, FRA	FRA	BEL, FRA	FRA
2017	FRA, ESP	FRA	BEL, FRA	FRA
2018	COL, FRA, ESP		BEL, FRA	

6 Conclusion

This paper has proposed a new approach to measure the risk of carbon leakage in two heavy industry sectors: cement and steel. Substitution elasticities at the product level are first estimated from a gravity model, finding values between 3 and 5 for all four products. These substitution elasticities are used as inputs to derive own- and cross-price elasticities which are in turn used as inputs in the hypothetical monopolist test.

This test returns a positive result on its first iteration for flat and steel products. This is in large part due to low observed margin rates, which could reflect an already competitive market and therefore induce a fallacy. The relevant market for hydraulic cement is found to be quite restricted and intra-european, while the relevant market for clinker is found to include countries from different continents - but still does not include more than 3 countries at a time.

Based on these results, it is difficult to provide any policy implications. While the negative result from the hypothetical monopolist test theoretically indicates that there is some form of market power at the national level for the heavy industries that are studied, the potential bias induced by the margin rate data would actually push for the opposite interpretation. As a result, further work should look into this bias and refine the methodology proposed in this paper.

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