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WORKING PAPER

Mind the Market: A Novel Measure of Carbon Leakage Risk

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Defining a fair and transparent measure of carbon leakage risk is essential to ensure the effectiveness of the EU's climate policies. This paper proposes a novel methodology to assess this risk, which takes market structure into account -- a key factor often overlooked in both academic research and policymaking. The methodology involves applying the micro-founded hypothetical monopolist test (or SSNIP test) at the country-product level. It allows for the definition of the relevant market for four products in the steel and cement industries. The inputs required for the hypothetical monopolist test are derived by estimating a product-level gravity equation. The findings from this study illustrate that market structure differs substantially at the product level, even within a single industry. Clinker appears as the product most at risk of carbon leakage. This suggests that carbon leakage risks should be computed by policymakers at a highly granular level and taking market structure into account.

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KEYWORDS

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Hypothetical monopolist
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Executive summary

The EU's industry makes up 22% of its total greenhouse gas (GHG) emissions. To stay in line with its objective of carbon neutrality by 2050, the EU must rapidly and significantly cut down these industrial emissions. While robust climate policies are essential to achieve this, the perceived risk of carbon leakage – the relocation of production to regions with laxer climate regulations – has been a contentious issue. If overstated, it could lead to inefficient climate policies by prioritizing industry protection over environmental impact. If underestimated, it could result in substantial leakage, negating environmental gains and harming industrial competitiveness.

A key question is therefore how to provide a fair and transparent measure of carbon leakage risk. Existing works have either defined carbon leakage risk through ex-ante models, generally assuming perfect competition in all sectors, or attempted to measure it ex-post through empirical works. Empirical studies have focused on periods when climate policies were fairly lax and therefore cannot provide insights into future carbon leakage risks when policies will be tightened.

This paper introduces a novel approach to measure carbon leakage risk: the application of the hypothetical monopolist test, or SSNIP test, at the country-product level. The proposed methodology offers several advantages compared to existing literature:

1. **Granular Analysis**: It allows for highly disaggregated product-level assessments and thus avoids the aggregation bias noted in this literature.
2. **Incorporation of Market Structure**: Unlike computable general equilibrium models, which assume perfect competition, this approach accounts for market structure, which is found to be of importance in empirical works on carbon leakage.

Empirical results focus on four industrial products: clinker, cement, and flat and long steel products. Clinker is the product associated with the highest leakage risks due to its homogeneity and low transportation costs, while hydraulic cement and steel products have narrower relevant markets, implying less substitution risks. Finally, long steel products have the lowest leakage risks, likely because of regional specialization by product specialty.

Three important policy implications can be drawn from this paper's findings:

1. When measuring carbon leakage risk, the following elements should be accounted for: the level of product homogeneity, regional specialization and trade potential rather than observed trade.
2. Measures of carbon leakage risk should be as granular as possible, as products within the same sector can have very different levels and types of risk.
3. There may not be a strong risk of climate policy impacts on exporters and the risk that does exist could be alleviated by elaborating common carbon standards and policies at the product level with strategically selected countries.

1 Introduction

The EU's industry makes up 22% of its total greenhouse gas (GHG) emissions (EEA, 2022). To stay in line with its objective of carbon neutrality by 2050, the EU must rapidly and significantly cut down these industrial emissions. Although ambitious climate policies are necessary to incentivize firms to decarbonize, concerns around the risk of carbon leakage have slowed their development. Trade associations invoke this risk to warn of competitiveness losses (Fagan-Watson et al., 2015),[1] while policymakers raise it as a threat to the effectiveness of climate policies (Draghi, 2024; European Commission, 2019, 2021). On the other hand, environmental groups dismiss it as a mere excuse used to block stringent climate policies (Carbon Market Watch, 2015). A true consensus on the magnitude of carbon leakage risk remains elusive in policy circles.

One of the key questions is how to provide a fair and transparent measure of carbon leakage risk. Defining such a measure is essential to design policies that effectively tackle carbon leakage *without* undercutting the impact of climate policies (Cosbey et al., 2019). Overestimating the risk of carbon leakage can hinder climate policies from having a real impact, while underestimating it can lead to heavy carbon leakage and losses both in terms of environmental and competitiveness outcomes. This paper contributes to the discussion by proposing a novel methodology to assess carbon leakage risk, one which accounts for market structure – a key factor often overlooked in both academic research and policymaking.

This paper takes the EU as a case study as it is a region with one of the world's oldest and most stringent carbon markets, the EU Emissions Trading Scheme or EU ETS (World Bank, 2023). The bloc has also implemented several "anti-leakage" measures hand-in-hand with its carbon market; these included the free allocation of allowances to sectors considered at risk of carbon leakage (European Parliament and Council, 2013), some compensation for indirect cost increases (European Commission, 2012), and more recently, a Carbon Border Adjustment Mechanism (CBAM; European Parliament and Council, 2023).[2] In each of these cases, the European Commission (EC) computed an indicator of carbon leakage risk to determine which sectors and products would be covered by anti-leakage policies.

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[1] See also the article entitled "Carbon leakage concerns dominate EU ETS debate" by ENDS Europe, a media focused on European environmental news, available at https://www.endseurope.com/article/1640202/carbon-leakage-concerns-dominate-eu-ets-debate?utm_source=website&utm_medium=social.

[2] Industrial installations at risk of carbon leakage received 100% of their allowances for free during the third phase of the EU ETS (2012-2020) and will continue to receive more than half of their allowances for free until 2030. Free allowances will be fully phased out by 2034 and replaced by a Carbon Border Adjustment Mechanism (European Parliament and Council, 2023).

This paper belongs to a vast strand of economic literature focused on carbon leakage. It was initially studied through the prism of game theory in Markusen's foundational papers (Markusen, 1975; Markusen et al., 1993), which showcase high risks of carbon leakage when a country unilaterally imposes a stringent climate policy on its producers. Carbon leakage was then transposed to computable general equilibrium (CGE) models, which calibrate behavioral parameters and elasticities to assess the risk of carbon leakage in various policy and geopolitical world scenarios. They tend to assume perfect competition in all sectors as a simplifying assumption to be able to model the world economy as a whole (Cameron & Baudry, 2023). However, this may not be an accurate reflection of industrial sectors' market structure which tends to be oligopolistic (Cook, 2011; Sourisseau, 2018). Due to their global coverage, CGE models also represent sectors at a fairly aggregated level, which induces a bias in measures of carbon leakage (Fischer & Fox, 2018; Sato et al., 2015). Overall, CGE models have found moderate carbon leakage rates, around 10 - 30% (Böhringer et al., 2012; Carbone & Rivers, 2017).

As climate policies have been increasingly implemented in different jurisdictions, empirical works have also emerged, evaluating whether these policies generated carbon leakage (Joltreau & Sommerfeld, 2019; Verde, 2020). They have generally uncovered low or null leakage rates (Cameron & Baudry, 2023; Caron, 2022). While these studies capture true market conditions given they study empirical data, they have mostly focused on time periods when climate policies have not been very stringent and industrial sectors were protected by anti-leakage policies. This could explain the low carbon leakage rates found. Since they are backwards-looking by nature, the results from empirical studies say nothing about *potential* leakage risk as climate policies become more stringent.

Today, the EU has over a decade of experience with anti-leakage policies and the measurement of carbon leakage risk. The EC measures carbon leakage risk based on two criteria: trade intensity and energy or carbon intensity. This measure has been criticized for overestimating the true risk of carbon leakage, leading to an overly generous allocation of free allowances and a muting of the EU ETS' price signal (De Vivo & Marin, 2018).

This paper aims to contribute to the literature evaluating carbon leakage risk by proposing a new approach: applying the hypothetical monopolist test – also known as the SSNIP[3] test (Werden, 2003) – on a country-product level. The hypothetical monopolist test provides a definition of a country-product's relevant market, i.e., the set of products and the geographic area in which a country's producers competes. This is defined by the extent to which consumers are willing to substitute between products in response to price changes. The larger

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

the relevant market, the more adequate substitutes are available to consumers. If stringent climate policies increase the price of domestic goods, consumers will easily be able to switch to alternatives from foreign producers, inducing carbon leakage. A wider relevant market is therefore associated with a higher risk of carbon leakage. Some of the parameters used in the test are estimates of a constant elasticity of substitution (CES) derived from a gravity model, which is linked both theoretically and empirical to the hypothetical monopolist test in this paper.

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 estimates, which avoids the aggregation bias found in this literature. Second, it simultaneously takes into account the impact of trade elasticities, like CGE models, and market structure – an element which has been omitted in most approaches so far but is found to be of importance in empirical evaluations of EU ETS sectors.

Results from this approach provide important insights into the EU's relevant market for four industrial goods: clinker, cement, and flat and long steel products. Clinker stands out as the product most at risk of carbon leakage, consistently showing the largest relevant market across all simulations due to its high homogeneity and low trading costs. In contrast, hydraulic cement has a more restricted relevant market. Both steel products have smaller relevant markets than the cement products studied in this paper. Flat steel products have the most limited relevant market of all four products, indicating greater product-level differentiation and regional specialization. The analysis also shows that EU producers are currently not highly competitive on foreign markets, which might indicate that the competitive impacts of domestic carbon pricing may be overstated. All of these findings underscore the importance of granular product-level analyses to assess carbon leakage risks and call for measures that consider the specific market structure of each product.

This paper first reviews how carbon leakage risk has been measured in existing literature (Section 2). Section 3 then provides contextual information on the products this paper focuses on, namely on their characteristics related to trade and carbon intensity. Section 4 presents the theoretical model that links the hypothetical monopolist test and the gravity model, as well as the empirical strategy that is used for the estimation of the latter. Section 5 describes the data used in this paper. Finally, Section 6 presents and discusses the main results of this analysis, and Section 7 concludes.

2 A review of carbon leakage measures

Defining a measure of carbon leakage risk is a difficult task for two main reasons. First, carbon leakage has never been empirically observed because climate policies have not been very stringent for most of the period that has been studied in the literature (Cameron & Baudry, 2023; Verde, 2020). This makes it difficult to apprehend the impacts a particular policy or carbon price level can have on firms, especially since effects may not be linear. Second, the design of these policies is contentious, because the details of their implementation make a big difference for firms that are covered by climate policies. Firms that were freely allocated their allowances in the first phases of the EU ETS were able to generate large rents by passing onto consumers the opportunity cost of these allowances (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).

Ex-ante approaches. 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 outcome parameters. These models have found variable, but generally low, leakage rates[4]. While game theory models allow for firms to act strategically, their CGE counterparts generally make the simplifying assumption that global industrial markets are perfectly competitive. Two studies notably depart from this assumption: Babiker (2005) and Balistreri and Rutherford (2012). Both papers find higher leakage estimates than the rest of the literature.[5]

Ex-post approaches. Empirical papers have attempted to quantify carbon leakage induced by existing climate policies. Overall, they have found almost no effect of climate policies – likely because these policies have not been stringent enough to induce this kind of an effect[6]. Generally, these empirical papers either study the economic outcomes of firms covered by climate policies or changes in trade flows caused by these policies. The most recent and robust study on this subject is the one by Dechezleprêtre et al. (2023), which finds that the EU ETS actually had a small but positive effect on firms' economic returns.

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

[5] See Cameron and Baudry (2023) for a more detailed discussion on this topic.

[6] See Dechezleprêtre et al. (2019), Joltreau and Sommerfeld (2019), and Verde (2020) for reviews of the literature on this topic.

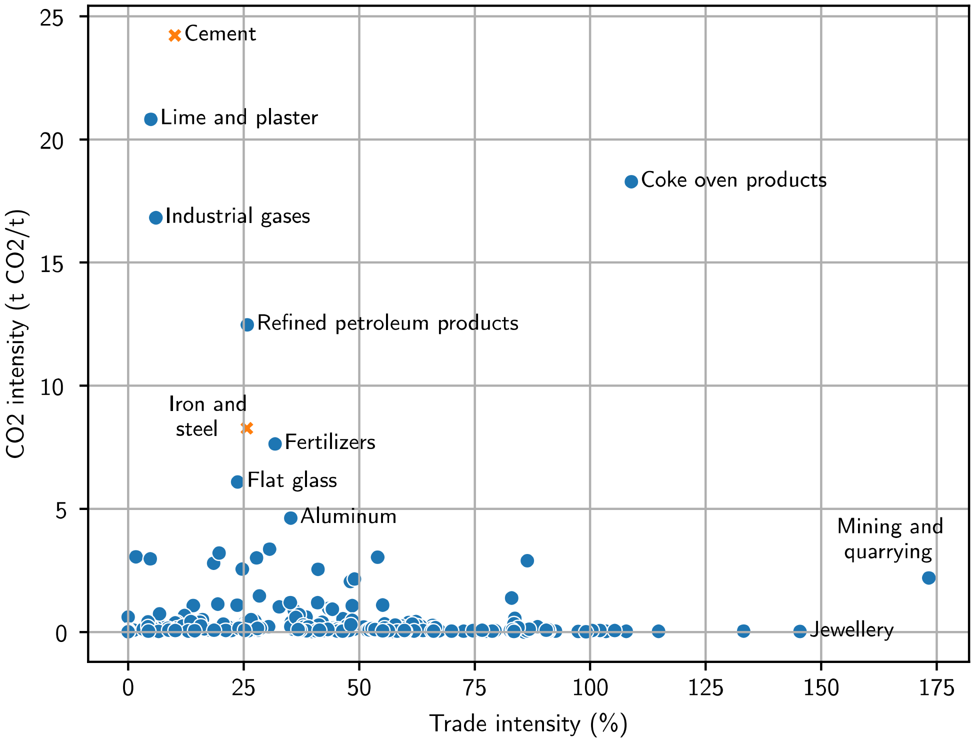
Additionally, Branger et al. (2016) develop an analytical demand model for cement and steel specifically, and find no evidence of carbon leakage in the first two phases of the EU ETS. More macro studies have also looked into country-level changes in emission patterns caused by climate policies, but have also found low or no carbon leakage (Aichele & Felbermayr, 2015; Naegele & Zaklan, 2019).

EU indicator. On the policy side, the EU measures the risk of carbon leakage based on sectors' trade and energy intensities. Trade intensity is used as a proxy of 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 costs imposed by the EU ETS. This criteria is fairly rudimentary, and is not based on any strong economic justification. Some literature has assessed the EU's methodology and proposed alternative criteria to measure carbon leakage risk. Overall, this strand of research tends to show that the EU's measure of carbon leakage overstates risks because it aggregates sectors too much (Fischer & Fox, 2018), omits any country-level (Sato et al., 2015) or firm-level (Martin et al., 2014) differences in exposure, does not accurately measure pass-through capacities (Sato et al., 2015), or foreign output elasticities (Fowlie & Reguant, 2018) and does not account for non-price trade barriers such as integrated production processes, service specification, or the location of resources used as inputs (Hourcade et al., 2007). Additionally, 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; Ganapati et al., 2020) and potentially being exacerbated by climate policies (Ryan, 2012).

3 Industrial context: cement and steel

The model proposed in this paper is applied to two heavy industry sectors: steel and cement. The choice of these sectors was driven by multiple factors. First, both sectors are central to the EU's decarbonization strategies. They are highly carbon intensive, and responsible for large amounts of emissions within the EU; cement and steel production are respectively responsible for 4% and 5% of the EU's total emissions (Marmier, 2023; Somers, 2022). Additionally, they have both been included in the list of sectors at risk of carbon leakage since the inception of the EU ETS. This is in part because of their high carbon intensity and the fact that they are considered "hard to abate" sectors, and in part due to their exposure to international trade, Second, it is interesting to look into these sectors comparatively because they present differing characteristics. Cement production is much more carbon intensive than steelmaking, while steel producers have a higher trade intensity than cement. Cement is not traded much over long distances given its heavy weight and resulting high transport costs. Figure 1 illustrates this by showing where cement and steel stand compared to other sectors deemed at risk of carbon leakage based on the EU's assessment.

Figure 1: European Commission carbon leakage indicator



Source: European Commission

Note: Data from 2013 to 2015, used to determine the carbon leakage list for Phase IV of the EU ETS.

Finally, these sectors work well with the theoretical underpinning and empirical implementation of the model proposed in this paper. An important characteristic of the model is its Armington trade structure.[7] The products from the cement sector are highly homogeneous, and are therefore substitutable to some extent no matter where they come from. The products from the steel sector are more heterogeneous, but the specialization between different products is country-specific, meaning the Armington structure of trade is also relevant (Carvalho & Sekiguchi, 2015; Herfort et al., 2010; Hourcade et al., 2007). Both industries are also

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[7] Armington structures of trade assume that products from different countries are imperfect substitutes. The extent to which products are differentiated by country of origin is measured by Armington elasticities, which are cross-elasticities between two products from different countries (Armington, 1969).

represented by international trade associations that collect and publish data on country-level production.[8] This data is needed for the empirical estimation of the gravity model in this paper. This section describes each of these sectors in more detail, providing information on their production process and emission patterns.

Cement. In this paper, the cement sector is composed of two products: clinker and hydraulic cement. To understand what these products are and what their emission profiles and abatement possibilities are, it is important to have a basic understanding of the cement-making process.

The manufacturing of cement begins with the mining and grinding of raw mineral materials, mostly limestone and clay. The resulting powder is heated to 1450°C. This 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. 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.

China is by far the largest producer of hydraulic cement and clinker, followed by India, the EU, Vietnam and the USA (Figure 2). Due to its high transport costs, most cement is produced and consumed domestically, meaning the sector is not very trade intensive. Figure 3 shows that for more than half of the countries in the data, 90% of cement products are consumed in the country where they are produced, leaving only a small share to be exported to other countries. Hydraulic cement is slightly more traded than clinker.

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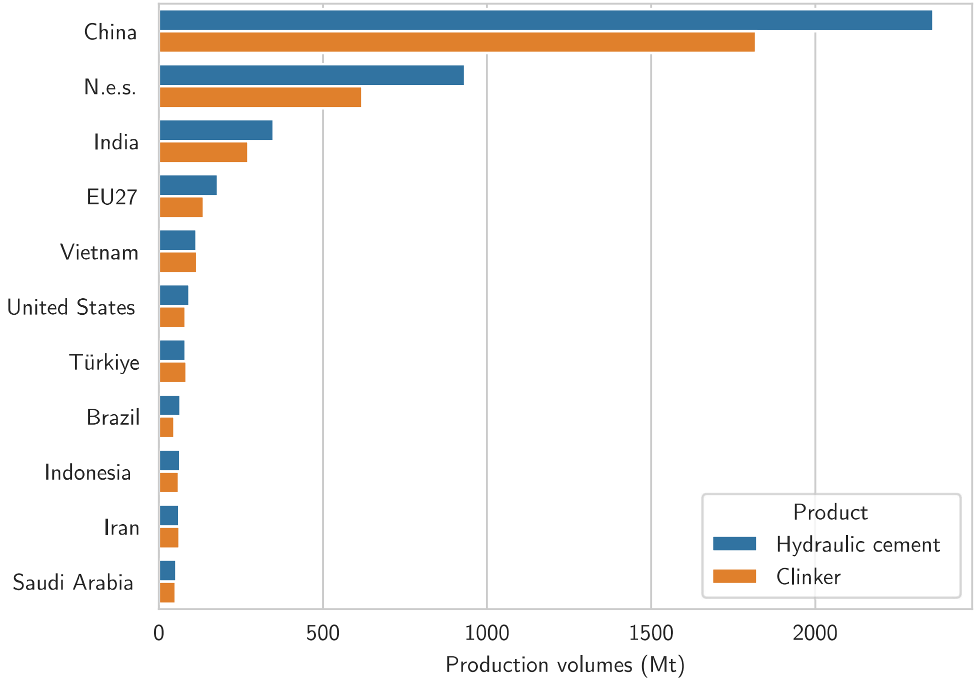
[8] The World Steel Association and the Global Cement and Concrete Association, respectively.

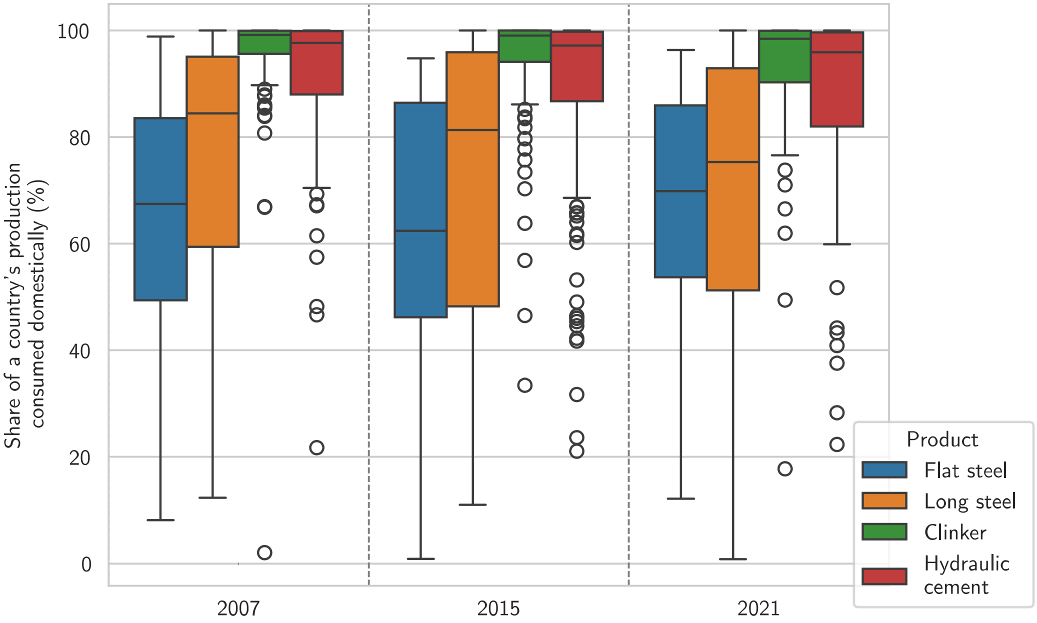
Figure 2: Top cement and clinker producing countries (2022)



Source: United States Geological Survey (2021)

Note: "N.e.s." sums all countries not elsewhere specified

Figure 3: Distribution of domestic consumption shares (2021, 2022)



Sources: Gaulier and Zignago (2010), United States Geological Survey (2021), and WorldSteel (2023)

Steel. The steel industry produces flat and long steel products. These categories of products are used for different types of final products, and have different production requirements that define the ways their production can be decarbonized.

In a schematic sense, the steelmaking process can be split into primary and secondary production. Primary production is based on the mining of iron ore, which is turned into iron either in a blast furnace (BF) or in a direct-reduction iron (DRI) furnace. This iron is then turned into steel either in a basic oxygen furnace (BOF), or in an electric arc furnace (EAF). Direct and indirect emissions related to the production of steel amount to 2 tons of CO2 via the BF-BOF route, or 1 ton of CO2 via the DRI-EAF route. Secondary production is based on the remelting of scrap steel in an EAF. Steel produced via this route directly and indirectly emits only an average of 0.34 tons of CO2 (International Energy Agency, 2020). However, secondary steel production does face a quality issue, as scrap can be mixed with other elements, which prevents its use to create high-quality steel.

While long products can generally be produced with this lower quality steel, some flat products require high-quality steel that can only be produced via the BF-BOF production route today.[9] This might mean these products are not equally sensitive to carbon pricing schemes, since flat products have less options for their decarbonization (Sardain, 2023). In terms of usage, flat and long steel products are also not substitutes. Flat products are generally used in car manufacturing and household appliances, while long steel products are generally used in infrastructure.

Once again, China is unquestionably the largest producer in the world of both products (Figure 4). While the EU's production is a lot more restricted, it is the second producer of both flat and long steel products, followed by the USA and Japan for flat steel products, and India and Japan for long steel products. Steel products are traded more than cement (see Figure 3) especially flat steel products, but are less carbon intensive (Figure 1). Relative to other industrial sectors however, they are still highly carbon intensive.

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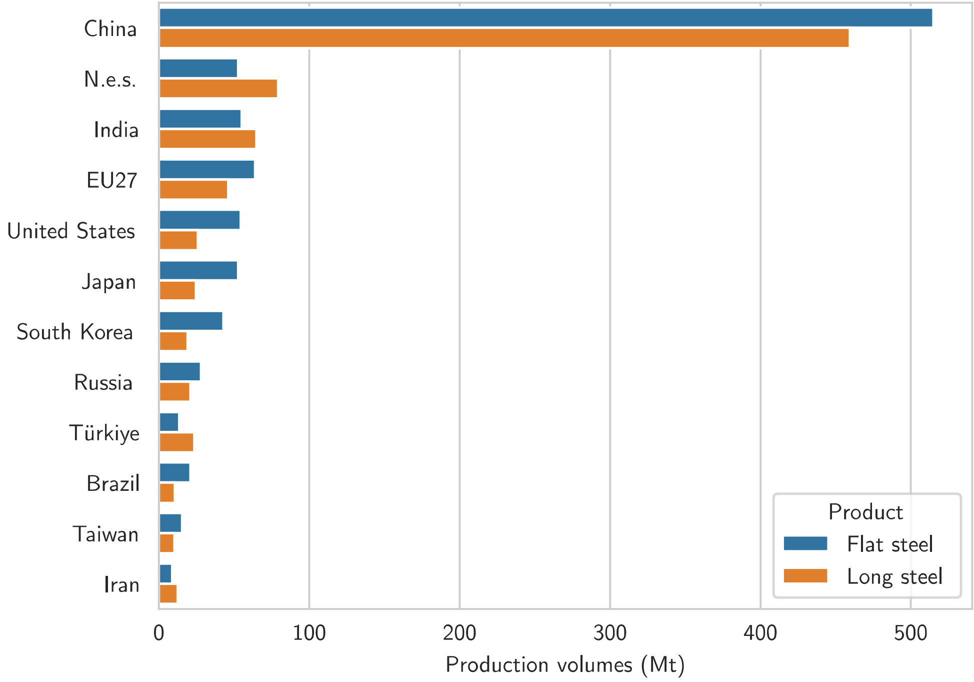
[9] See the article by an industry specialist on Project Blue, available at https://web.archive.org/web/20240525173158/https://projectblue.com/blue/news-analysis/525/why-could-steel-industry-de-carbonisation-be-long-and-difficult

Figure 4: Top steel producing countries (2021)



Source: WorldSteel (2023)
Note: "N.e.s." sums all countries not elsewhere specified

4 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 products (such as cement or steel). The downstream producers buy industrial products from the upstream producers and use them as inputs, with labor, to produce final products (such as construction materials or cars). An Armington (1969) structure of international trade for the industrial product (hereafter the product) is assumed, meaning varieties of the product are differentiated by country of origin and each country only produces one variety. In this set-up, indexing by upstream producer, country or product variety 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. In this paper, it is applied at a more aggregated country-product level. The test delineates an upstream producer's relevant market 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. These elasticities are therefore derived from the second part of the model, a gravity model applied at the country-product level. The gravity model is helpful in this setting because it requires relatively little data given that most characteristics are controlled for by fixed effects. Additionally, it is separable both theoretically and empirically (Yotov et al., 2016). The main characteristics of each part of the model are described hereafter, and a full derivation can be found in Appendix B.

4.1 Part one: the Hypothetical Monopolist Test

The hypothetical monopolist test is an iterative method that defines the relevant market for one particular product and country. To define a relevant market, the test finds all the varieties – i.e. country of origin – of a product that consumers consider to be adequate substitutes. These substitutes are defined according to the following rule: if a single entity (the hypothetical monopolist) were producing all of them, it could increase its sales price without reducing its profit because consumers consider all varieties *outside* of those the hypothetical monopolist produces to be inadequate substitutes. This means the relevant market is properly defined, and the products included in the test compete directly with one another. On the other hand, if the test finds that the hypothetical monopolist would reduce its profit if it increased its sales price, then there is at least one variety outside of those produced by the hypothetical monopolist that consumers are switching to.

Taking a country $j \in \{1, ..., N\}$ as a starting point, the test's first iteration checks whether a hypothetical monopolist controlling the production of product j could profitably increase the price of this product. If the result is positive, this means the relevant market for producers in j is only made up of the national market. If the result is negative, this means that there are substitutes outside of j that consumers are turning to following the price increase in j. In this case, the test is run again with a broader definition of the hypothetical monopolist: it does not only include j but also an additional substitute $i \in \{1, ..., N\}$, with $i \neq j$. The specific i that is included in the following iteration of the test is the country that has the highest likelihood of being a competitor to j. This is determined by taking the product of each country's production volume and its cross-price elasticity with j;[10] this measure proxies the magnitude of a potential transfer of consumption from j to i.

If the hypothetical monopolist can impose a price increase on j and capture all substitution to i, without losing out to any other non-i substitutes, then the relevant market has been

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[10] The definition and estimation strategy for the cross-price elasticity is described in Section 4.2.

found. If not, an additional substitute $i+1$ needs to be added into the definition of the hypothetical monopolist. This will be the country that is the second most likely to be a competitor to j, as defined above. The test is run until it returns a positive result, with an additional substitute added at each iteration. When the test returns a positive result, the hypothetical monopolist controlling the production of product j and its substitutes $i \in \Theta_j = \{1, ..., N'\}$ can impose its market power on this market, with Θ_j the subset of products that are adequate substitutes to j. At this point, the test is stopped and the relevant market for j is composed of j and Θ_j.

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 $+5\%$ of the observed price.[11] The observed price is presumed to be the result of a competitive equilibrium. In other words, the test checks whether profits Π 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). 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 consumption leakage, since it represents the amount of consumption transferred from country j to another country i after a price increase in j. Formally, the condition for the hypothetical monopolist test is written as:

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

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

At each iteration, this is equivalent to testing for the following condition (see Appendix B.1 for a full derivation of this result):

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

Where ε_{jj} is country j's own-price elasticity, ε_{ji} is country j's cross-price elasticity with country i, μ and v are the margin rates and turnover, respectively, and x is the price increase imposed by the hypothetical monopolist. The expression on the right-hand side of

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[11] The threshold of 5% is standard in the literature as it is considered a small but significant price increase. I also include simulations of other levels of price increases in the results.

the inequality is known as the "critical elasticity". If the negative of a country's own-price elasticity is smaller than the critical elasticity, then the hypothetical monopolist condition is verified.

If condition 3 is not verified, another iteration of the test is run, adding an additional substitute i. If it 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.

There is some uncertainty in the data I use for μ because the only data available is for the EU. To mitigate this uncertainty, I run the hypothetical monopolist test in a Monte Carlo simulation. For each iteration of the simulation, I assign a random value of μ to all countries, based on the distribution parameters of the EU's data and run the entire hypothetical monopolist test. The values I report as results of the test are therefore the share of simulation outcomes in which a country appears in the EU's relevant market.

4.2 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 products from an upstream producer rather than a consumer buying consumption products 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 specifies the substitution between labor and the aggregate industrial product and is defined as:

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

Where L is labor and M is the aggregate industrial product. The aggregate industrial product has N different varieties, one for each country/upstream producer in the world. The lower level of the downstream producer's production function describes how it produces the aggregate industrial product using different varieties of the upstream product as inputs. It 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 product, 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 product are substitutes rather than complements. Downstream producers therefore do not necessarily need to consume all varieties of the industrial product 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 B.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 product 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 B.2, the trade flow in monetary units X_{ij} of the industrial product 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 product in country i, O_i, is equal to the sum of its exports to all countries $(j \neq i)$ and to itself $(j = i)$ - i.e., domestic sales, also known as intra-national trade:

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

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). Given the highly specific nature of the industrial goods covered in this study, the main specification does not include these cultural variables.[12] Transport costs are defined as in equation 9 below, with δ_j importer j's distance coefficient and $dist_{ij}$ the geographical distance between countries i and j.

$$t_{ij} = \delta_j dist_{ij} \tag{9}$$

From this framework, the gravity equation that is used for estimation is derived. A Poisson Pseudo-Maximum Likelihood estimator with importer-year $\varphi_{i,t}$ and exporter-year $\chi_{j,t}$ fixed effects is used.[13] Appendix B.2 details the steps to reach the following expression of the gravity equation:

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

Own- and cross-price elasticities. I derive expressions of country j's own- and cross-price elasticities from the same monopolistic competition framework (see Appendix B.2). These elasticities are dependent on the CES substitution elasticity σ between varieties, the Cobb-Douglas parameter α for the industrial product and prices of the different varieties:

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

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

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[12] Trade in industrial goods requires highly specialized equipments and is therefore likely driven more by country specialization than these cultural distance indicators. However, to stay in line with the general gravity literature, I report regression results with these indicators in Appendix C.1. I use the standard indicators of cultural distance, including whether two countries have a Regional Trade Agreement, whether they have an official language in common, whether they are contiguous and whether they share colonial ties. While the cultural distance indicators have coefficients that are contrary to what is expected, including them does not substantially change the value or significance of the coefficients associated with the log distance between countries.

[13] I use the "ppmlhdfe" command in Stata, developed by Correia et al. (2020).

5 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. In this section, I begin by describing the data used in the gravity model. I then turn to the data used for the hypothetical monopolist test, which includes outputs from the gravity model.

5.1 Gravity model data

5.1.1 International trade data

The main source of data used for the gravity model is CEPII's BACI dataset (Gaulier & Zignago, 2010).[14] It contains data on quantities and values of international bilateral trade flows for 150 countries between 1995 and 2022. The HS07 version of this dataset is used.[15] This version was last updated in February 2024, and spans from 2007 to 2022.

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, there are still some variations in unit values that seem implausible and are likely caused by misreporting in the original data.[16] 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, I implement a procedure 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 Line" database, the procedure aims to capture outliers based on two dimensions: temporal and geographical.

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

[15] The Harmonized System (HS) is an internationally standardized nomenclature for traded products. 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.

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

I apply the following criteria to identify outliers:

- 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.
- Quantities that are 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.

The unit value and the quantity of flagged trade flows are dropped. The unit value is replaced by the importer-exporter median unit value if it is available, or the importer (or exporter) median unit value if it is not. Missing quantity values are then replaced with the ratio between the value of the flow and the updated unit value.

Finally, the dataset is aggregated to a product level.[17] Cement is classified as either clinker or hydraulic cement and steel products are split into flat or long products.

5.1.2 Intra-national trade data

To be theoretically consistent, gravity models require intra-national trade data. Intra-national trade represents the volume of products that a country both produces and consumes domestically. While most countries do not report direct measures of intra-national trade, a common way to measure this variable is to take the difference between a country's gross production of a product and the sum of its exports of that product to other countries (Yotov et al., 2016).[18]

Some databases use this method to provide intra-national trade data at a relatively aggregated level – generally the 2- or 3-digit level of the Industrial Standard Industrial

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[17] Appendix A.1 provides a correspondence table between HS codes and the products in this study.

[18] Canada is a notable exception to this. The Government of Canada provides data on trade between provinces that has been used in some of the foundational studies in gravity economics (see McCallum (1995) for example).

Classification (ISIC).[19] 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 that has been noted in the gravity literature (Anderson & van Wincoop, 2004; Anderson & Yotov, 2010).

For flat and long steel products, data from WorldSteel's online Statistical Yearbooks is used (WorldSteel, 2023).[20] These yearbooks provide data on the gross volume of production of flat and long steel products by country from 2006 to 2022.

For hydraulic cement, data from the United State's Geological Survey's Cement Statistics and Information is used – namely the Minerals Yearbook (United States Geological Survey, 2011, 2016, 2021).[21] This source provides data on the production of hydraulic cement by country between 2004 and 2021.

Comprehensive clinker production data is currently still lacking. 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 the data covers.[22] To work around this, I estimate clinker production volumes 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 A.3 provides a comparison of the constructed clinker production data with the GCCA's data. For consistency, I use the constructed data for all countries.

This production data was merged with the international trade data from BACI to generate intra-national trade flow volumes, using the product crosswalk shown in Appendix A.1.

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[19] 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.

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

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

[22] 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.

5.1.3 Distance

The data for the geographic distance indicator is taken from the CEPII's Gravity database and is the straight-line geographic distance between the most populated city of each country, in km (Conte et al., 2022).

5.2 Hypothetical monopolist test data

5.2.1 Own- and cross-price elasticities

As shown in equations 11 and 12, own- and cross-price elasticities are computed based on three elements: the CES elasticity of substitution between varieties of a product σ, the Cobb-Douglas parameter α, and prices for each variety.

CES trade elasticity of substitution. Product-specific CES trade elasticities of substitution σ are derived from the gravity model (equation 10). Table 1 reports the results of the gravity regression. σ is 1 minus the coefficient of the log distance variable. Values of σ are reported in Table 2. Figure 5 compares this paper's estimates of σ to those found in other papers, showing they are fully in line with existing literature.

Table 1: Gravity regression estimation results

	(1) Hydraulic cement	(2) Clinker	(3) Long steel	(4) Flat steel
Log distance	-4.845***	-5.440***	-3.287***	-2.308***
	(0.697)	(1.296)	(0.331)	(0.237)
Observations	22491	7603	18031	17486
Pseudo R^2	0.98	0.98	0.98	0.95
Fixed effects:				
Exporter-year	Yes	Yes	Yes	Yes
Importer-year	Yes	Yes	Yes	Yes

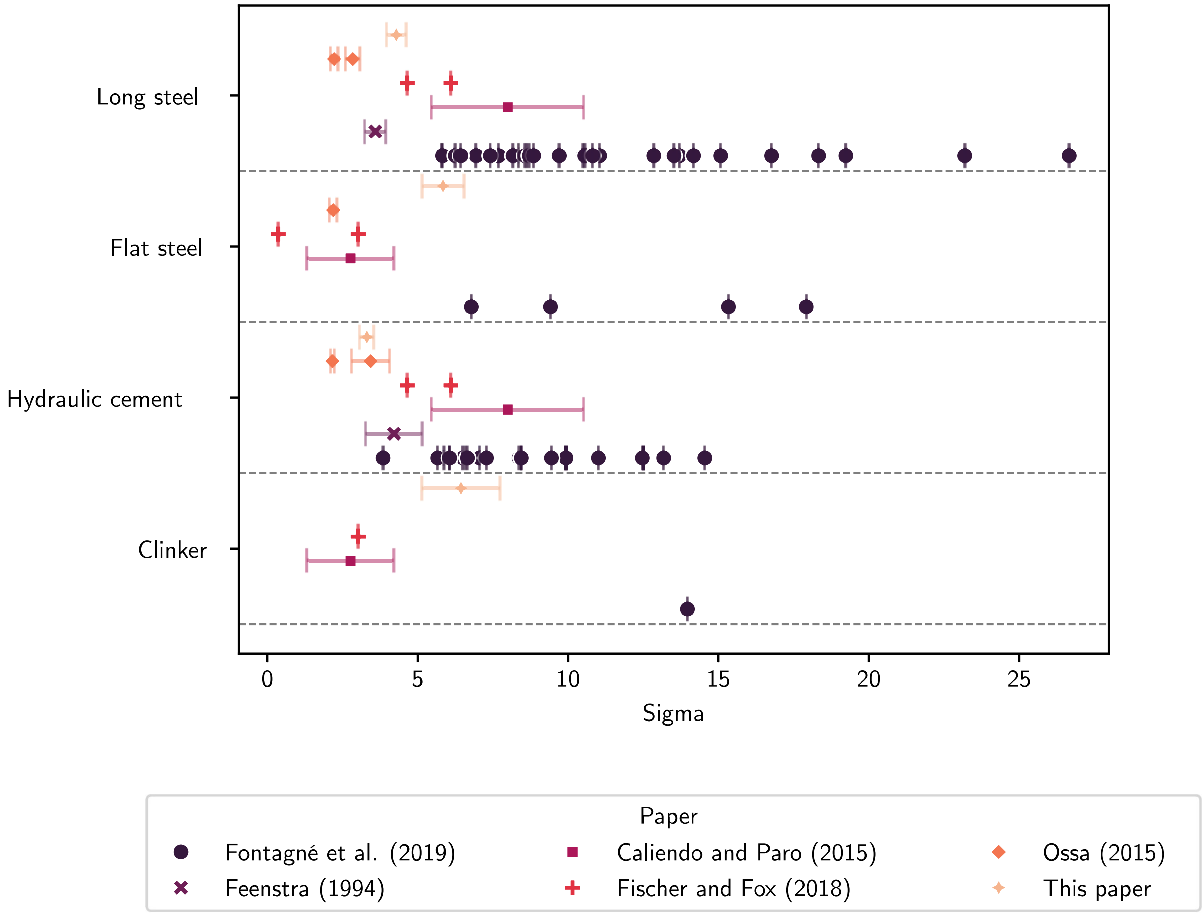
Note: Standard errors clustered by importer-exporter pair. Standard errors in parenthesis. Estimation through Poisson Pseudo Maximum Likelihood estimator.
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 2: Values of σ

	(1)	(2)	(3)	(4)
	Hydraulic cement	Clinker	Long steel	Flat steel
σ	5.845^{***}	6.440^{***}	4.287^{***}	3.308^{***}

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Figure 5: Comparison of trade elasticities



Note: Some of the elasticities displayed in this graph are estimated at a more aggregated level than those estimated in this paper. In this case, the elasticity is attributed to all the products included in the higher level of aggregation. For example, Caliendo and Parro (2015) estimate elasticities for "Basic metals". This estimate is therefore attributed to both flat and long steel products in this figure. Appendix A.4 provides all the values used in this graph, as well as the original product level at which each elasticity was estimated.

Cobb-Douglas alpha parameter. The α parameter is derived from the University of Groeningen's WIOD input-output database.[23] 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.

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 covered in this paper, 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.[24] An average correlation of 71% and 51% was found between the two datasets for flat and long steel products respectively. There is no reliable data the domestic pricing of hydraulic cement or clinker that could be used to compare with the constructed data.

5.2.2 Turnover and margin rate

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.[25] I use this data as a base, and perform a Monte Carlo simulation that assigns a random value to each country at each iteration. The random values is taken from a normal distribution with the parameters of the observed distribution in the EU. This mitigates some of the uncertainty around this parameter. If any bias exists in the in the EU's data, this bias is applied to all countries equally and therefore should not change the results of the hypothetical monopolist test, which compares countries to each other.

Turnover is calculated by multiplying the production data presented in Section 5.1.2 with unit values presented in section 5.1.1.

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

[24] See Appendix A.2 for a correlation analysis of the constructed data compared to the OECD's data.

[25] 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.

6 Results

6.1 Presentation of results

This section presents the main results from the hypothetical monopolist test. I first present results showing the EU's relevant market, then turn to results showing countries for which the EU is in the relevant market. All of the results are shown as world maps, with the shade of color representing the share of simulation outcomes in which a country appears. For example, if a country is shaded in the color representing 25-49%, this means that country has appeared in a quarter to half of all results from the Monte Carlo simulation.

5% price increase. First, I show results with a 5% price increase in the hypothetical monopolist test (Figure 6). Among the 4 industrial products that are covered, only clinker appears to face competition from countries outside the EU at this level of price increase. The 11 countries that appear within the EU's relevant market for clinker in more than half of all simulation results are Egypt (60%), Russia (55%), China (55%), Switzerland (55%), Colombia (55%), the UK (55%), India (55%), Türkiye (55%), the US (55%), the Philippines (55%), and Canada (50%). For the other three products that are covered, all other countries outside of the EU appear in less than a quarter of all simulation results.

10% price increase. When I change the price increase to 10% in the simulation, results only change in the cement sector (Figure 7). For hydraulic cement, some countries begin to appear in more than a quarter of simulation results. These include (in decreasing order of frequency): Egypt, Russia, Moldova, Brazil, Norway and Morocco. For clinker, the same countries appear as they did for the 5% price increase, with the addition of the United Arab Emirates, Thailand, South Africa, Algeria, Norway and Vietnam – all of which appear in around 55% of simulation outcomes. An additional 22 countries appear in 25 to 49% of simulation outcomes, with Serbia, Morocco, Tunisia, Ukraine and Indonesia appearing the most. For steel products, the EU's relevant market remains confined to itself.

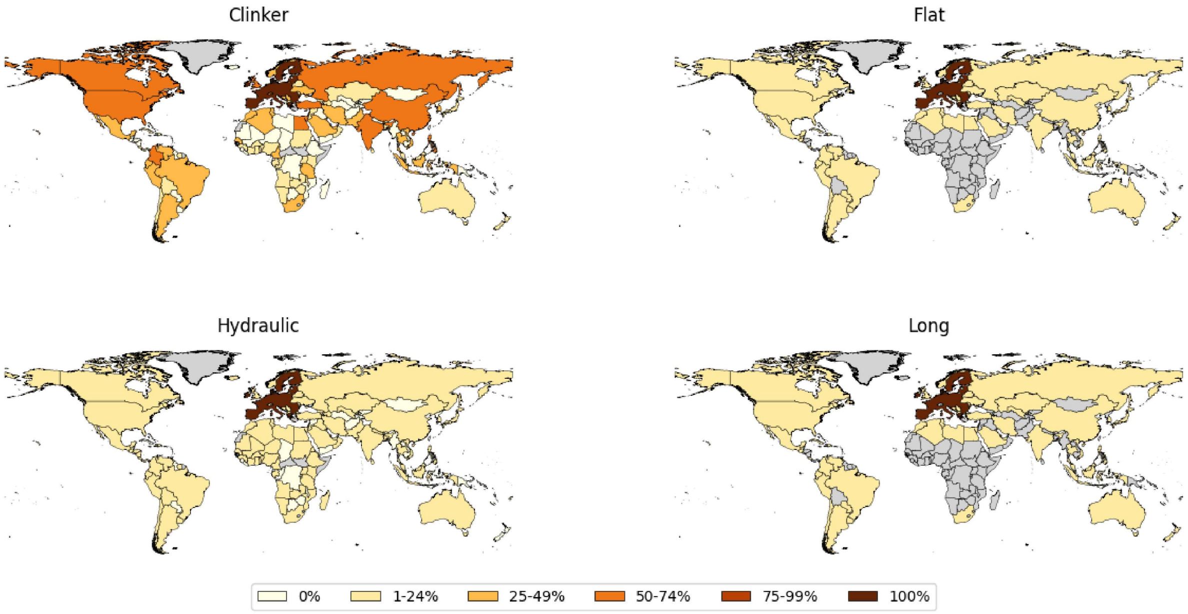
20% price increase. The results for a 20% price increase show a clear shift for long steel products (Figure 8). There seems to be a tipping point for long steel between a 10 and 20% price increase that makes the EU's relevant market significantly expand. With a 20% price increase, 7 countries appear in more than 50% of simulation outcomes: Egypt, Morocco, Moldova, Russia, Brazil, Montenegro and Norway. An additional 33 countries now appear in more than a quarter of simulation outcomes. The relevant market for flat steel products remains confined to the EU, even with a 20% price increase.

For clinker, Egypt is the country that appears the most in simulation outcomes (80%). The countries that appear the most frequently after Egypt are Russia, Switzerland, China, Colombia, the UK, India, the Philippines, Türkiye and the US. They appear in around 60% of simulation outcomes. 15 other countries appear in more than half but less than 60% of simulation results for clinker. For hydraulic cement, all countries remain below the 50% threshold. Egypt also appears the most frequently for this product, followed by Russia, Norway, Brazil, Moldova, Ivory Coast, China, Canada, Mexico, South Africa and Kazakhstan. An additional 31 countries appear in more than 25% but less than 30% of simulation outcomes.

50% price increase. Finally, I present the results for the EU's relevant market when the price increase is raised to 50% (Figure 9). While this represents a fairly implausible scenario, it is useful to illustrate the upper bounds of the EU's relevant market. Indeed, if a country is not in the EU's relevant market when the bloc experiences a 50% unilateral price increase, there is probably a reason for this. The variety that specific country produces may be too different from the EU's for EU consumers to ever consider it a relevant alternative, no matter the price differential.

For clinker, hydraulic cement and long steel products, results with a 50% price increase are in line with those presented with lower levels of price increases. The same countries appear most frequently in the EU's relevant market – although this frequency has itself increased. At this level, flat steel products also seem to have gone past a tipping point after which countries outside the EU enter the relevant market. The countries that appear in more than 50% of simulation outcomes are Egypt, Morocco, Russia, Brazil, Montenegro, Norway, Kazhakstan and Moldvoa, in decreasing order of frequency.

Figure 6: EU relevant market with a 5% price increase



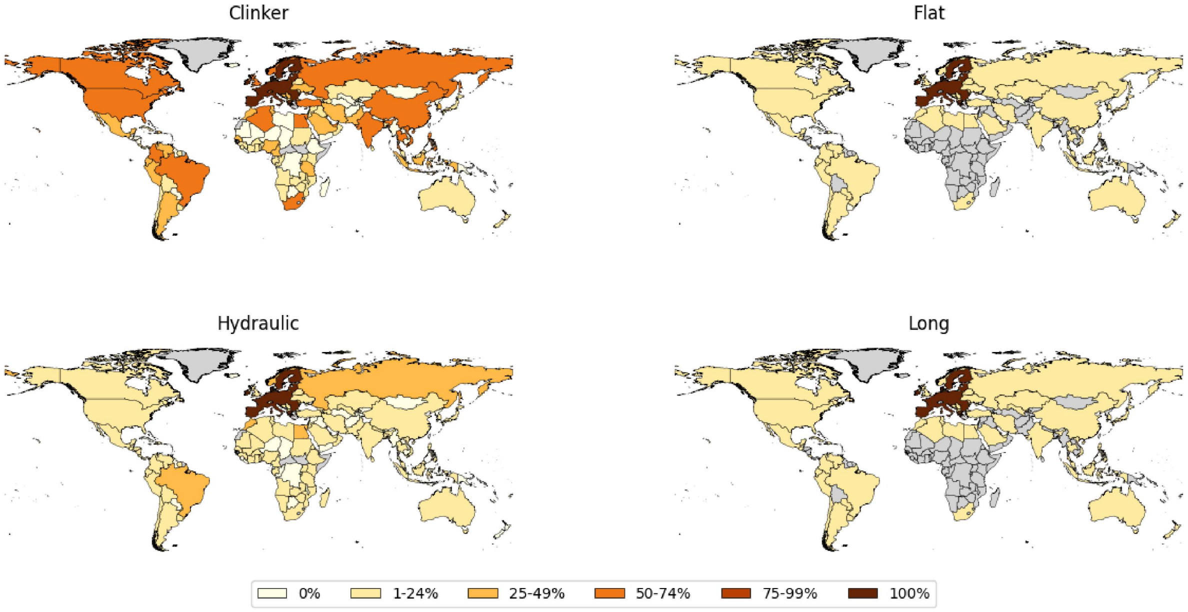
Clinker

Flat

Hydraulic

Long

Figure 7: EU relevant market with a 10% price increase



Clinker

Flat

Hydraulic

Long

Figure 8: EU relevant market with a 20% price increase

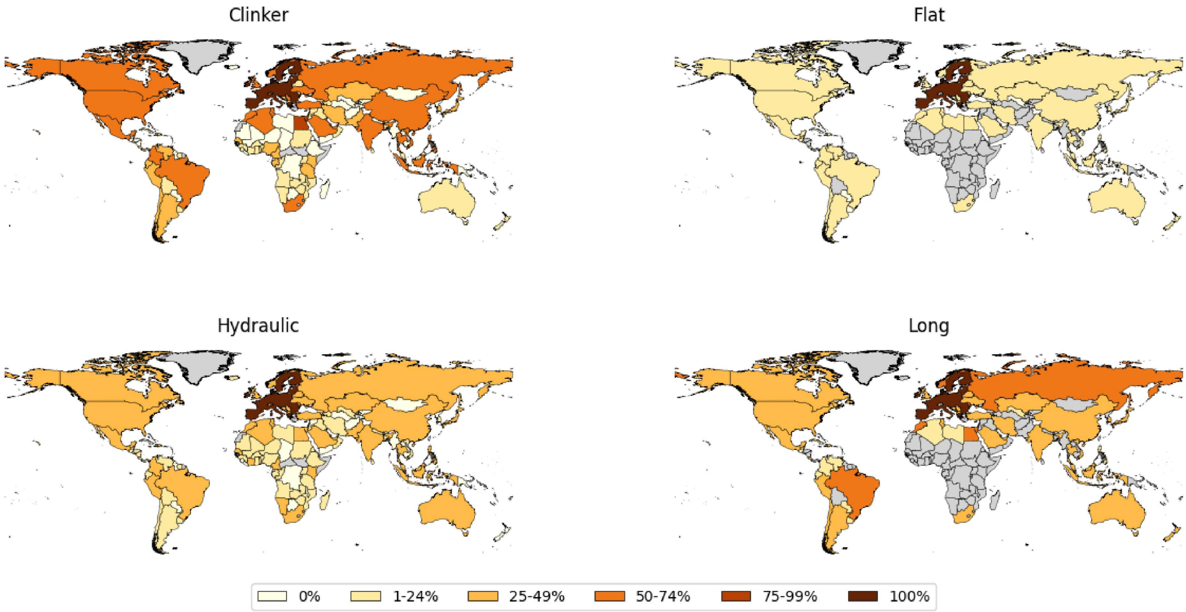
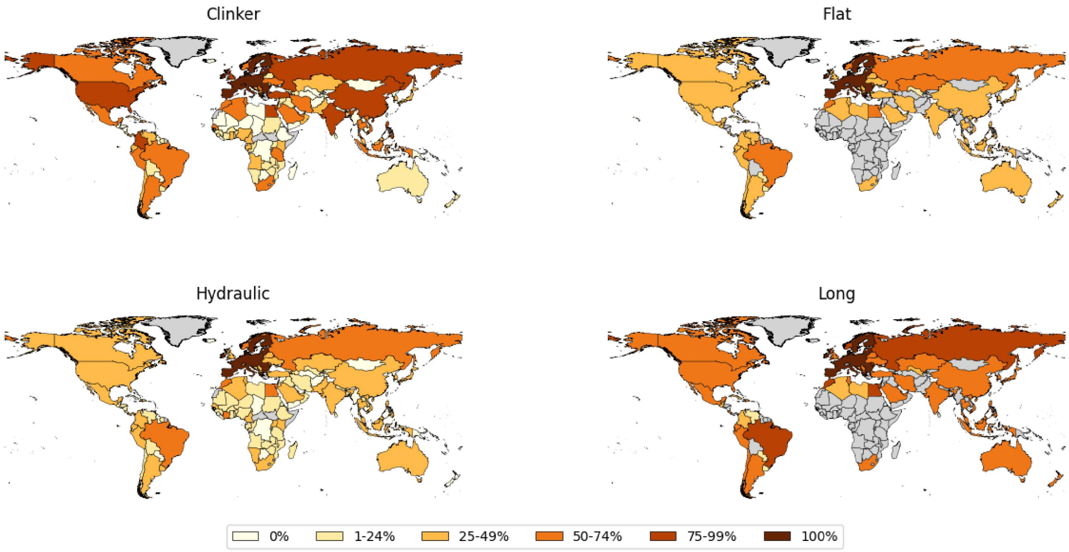


Figure 9: EU relevant market with a 50% price increase



EU exporters. The methodology used in this paper also gives insights on the relevant markets that EU exporters operate in. By applying the hypothetical monopolist test to different base countries (replacing the EU in previous results), I can determine their respective relevant markets. If the EU is included in this relevant market at low levels of a price increase, this indicates the competitiveness of the EU on the market as it is able to provide a suitable substitute to consumers. On the other hand, if the EU does not appear in the new base country's relevant market, this indicates that the EU's product is not sufficiently substitutable to be competitive.

With a 5% price increase in the hypothetical monopolist test for clinker, the EU is in more than a quarter of simulation outcomes for a number of countries, mostly on the African continent – including in more than 50% of simulation outcomes for Mali and Cameroon (Figure 10). As the price increase is raised to 20% (Figure 11) and 50% (Figure 12), this remains fairly consistent – most countries that have the EU in their relevant market are in Africa – with the addition of Russia, Myanmar, Australia and Brazil. Hydraulic cement shows similar patterns for these three levels of price increases, with the difference that the EU begins to appear in other countries' relevant markets at a higher level of price increase.

Turning to steel products, results for both flat and long products are similar to each other. With a 5% price increase, almost no countries have the EU in their relevant market in more than 25% of simulation outcomes – except Algeria for long steel products (Figure 10). At the 20% level, a few more countries appear, namely China, the US and Colombia (Figure 11). Finally, with a 50% price increase, the EU appears in more than 90% of the US's simulation outcomes for flat products, 80% of India's. It also appears in nearly 60% of simulation outcomes for China, the UK, Vietnam, Canada and Korea (Figure 12). This indicates that there is a threshold between 20 and 50% where the EU becomes significantly more competitive on international flat steel markets. For long products, the same countries appear as in the 20% price increase results: China, the US and Colombia are the countries for which the EU appears the most frequently – 66, 62 and 50% respectively.

Figure 10: Countries where EU is in relevant market with a 5% price increase

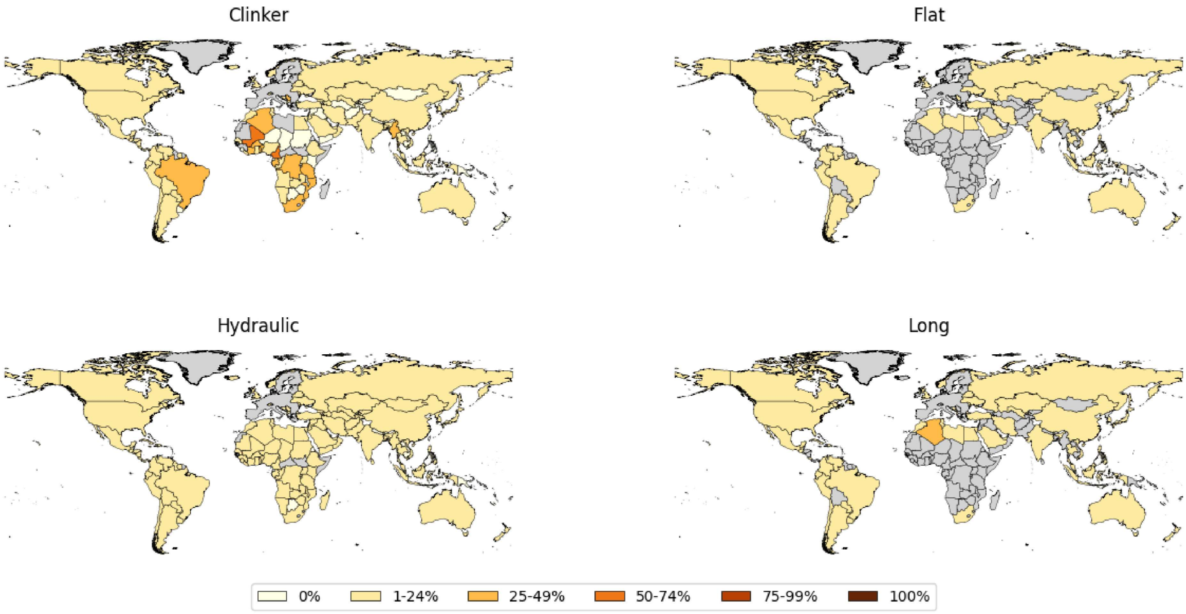


Figure 11: Countries where EU is in relevant market with a 20% price increase

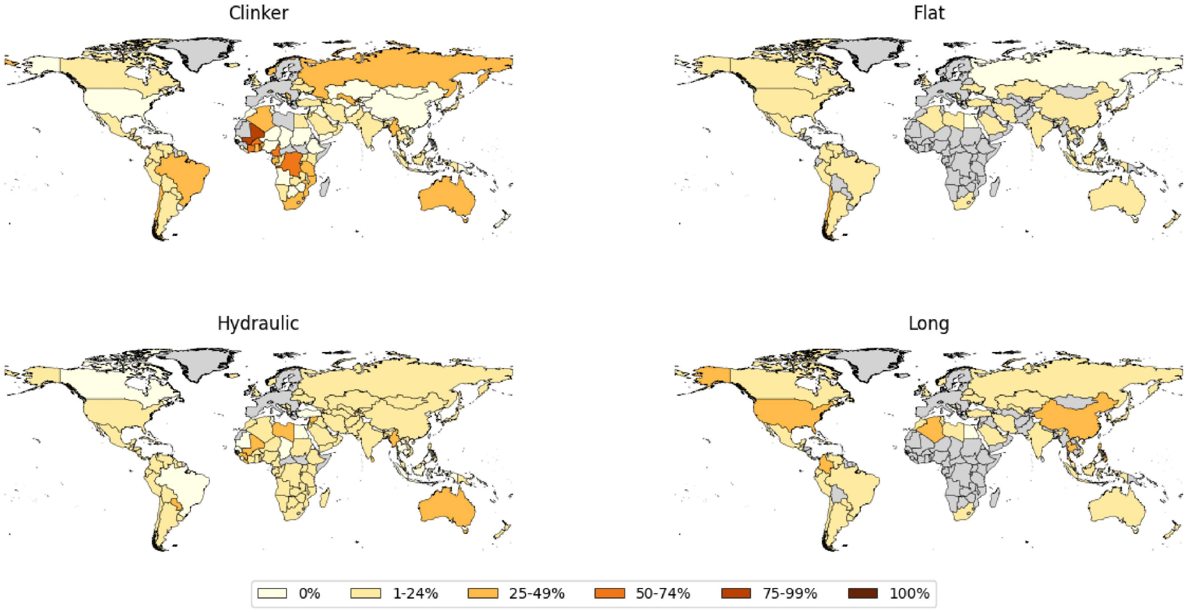
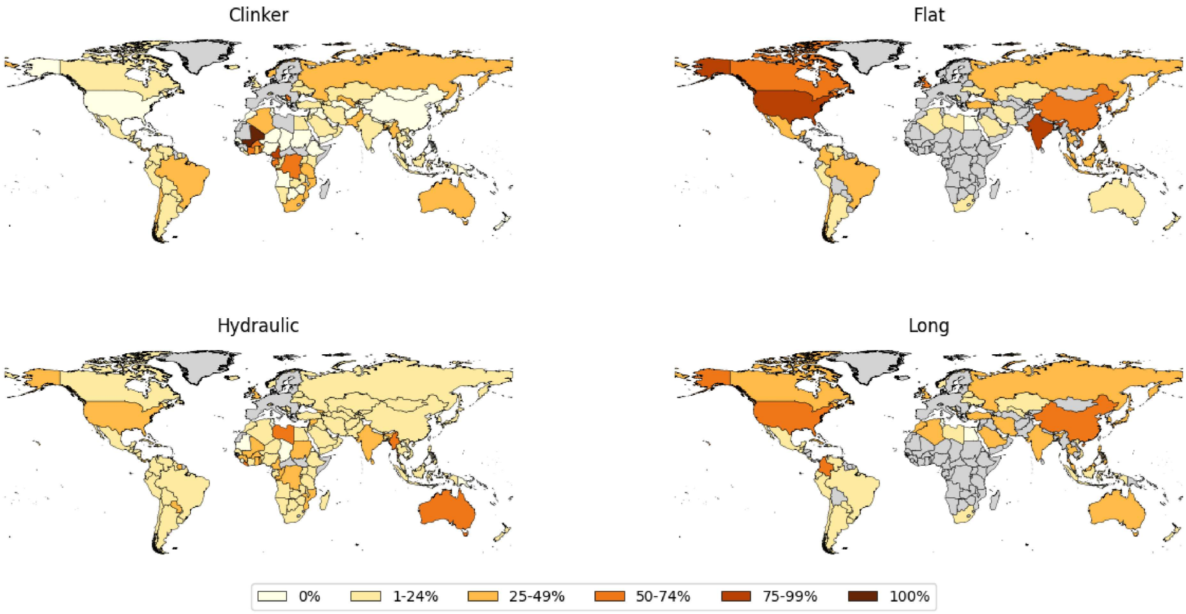


Figure 12: Countries where EU is in relevant market with a 50% price increase



6.2 Discussion and policy implications

This subsection discusses the results presented above and their policy implications. This study's results underscore notable differences in the market structure of clinker, cement, and steel products. Three important policy implications can be drawn from these findings. First, when measuring carbon leakage risk, the following elements should be accounted for: the level of product homogeneity, regional specialization and trade *potential*. Second, this measure should be as granular as possible as products within the same sector can have very different levels and types of risk. Third, there may not be a strong risk of climate policy impacts on exporters and the risk that does exist could be alleviated by elaborating common carbon standards and policies at the product level with strategically selected countries.

Among the four industrial products covered by this study, clinker emerges as the product with the highest level of carbon leakage risk in the EU, followed by hydraulic cement, long steel, and flat steel products. Clinker has the most countries in the EU's relevant market at the lowest level of a price increase (5%). Hydraulic cement begins to have more countries in the EU's relevant market at the 10% level, while the threshold for long steel products is between 10 and 20%, and is above 20% for flat steel products. This ranking reflects differences in product homogeneity, regional specialization and trade potential.

In the EU's current methodology to determine carbon leakage risk, the level of product homogeneity and market specialization are not taken into account. In this methodology, these elements are captured by the Armington elasticity – which represents the cross-price elasticity between two specific countries. This type of indicator could be included in the EU's methodology to better reflect carbon leakage risk based on each product's characteristics.

Product homogeneity. Clinker is the most homogeneous product of all four products analyzed in this paper. Since the 2000s, the chemical composition of this material has been stabilized, making it highly homogeneous across different countries (Herfort et al., 2010). Hydraulic cement is more homogeneous than steel, but less than clinker. Depending on their composition, different types of cement will have different applications and qualities (Kurdowski, 2014). The HS codes associated with these products perfectly show their different levels of homogeneity: clinker is only associated with one 8-digit code, while cement is associated with three, and flat and long steel products are each associated with five 4-digit codes, themselves each made up of two to eight 8-digit codes (see Appendix A.1).

A product's level of homogeneity can significantly impact its carbon leakage risk. It is more likely that EU consumers find acceptable alternatives outside of the EU for a homogeneous product like clinker than for highly differentiable products like steel. This makes it easier for foreign clinker producers to enter or increase their presence on the EU market if domestically-produced products become relatively more expensive.

Regional specialization. Since clinker is highly homogeneous, it is not possible for individual producers to specialize in significant ways to cater to specific markets. Specialization is slightly more prevalent in hydraulic cement, and is especially notable in the production of steel. Different countries and regions of the world have specialized in the production of different types and grades of steel (Carvalho & Sekiguchi, 2015; Steel Plate & Sections, 2024).[26] Flat steel products require higher-quality grades of steel than long

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[26] See also the blogpost entitled "Green steel transition in focus: Key takeaways from Eurometal Steel Day in Zurich" by Fastmarkets, available at https://www.fastmarkets.com/insights/green-steel-transition-in-focus-key-takeaways-from-eurometal-steel-day-in-zurich/ and the webpage entitled "Steel from Around the World: Types of Steel" from Steel Plate & Sections available at https://sps-bmsteel.co.uk/article/steel-from-around-the-world.

products do.[27] As a result, flat steel products can almost only be produced via a Blast Furnace – Basic Oxygen Furnace (BF-BOF) route while long steel products can be produced via the BF-BOF route as well as the Electric Arc Furnace (EAF) route.[28] This means that countries that have specialized more in EAF technologies would have to switch to BF-BOF if they want to compete on flat steel markets.

Observed trade versus trade potential. The EU's measure of carbon leakage relies on a measure of trade intensity as a proxy of the international competition a sector faces. However, this indicator is backward-looking and does not represent *potential* competition that a sector could realistically face given slight changes in prices or other circumstances. The methodology presented in this paper can complement the EU's measure by providing indications on trade and competition *potential*.

Using the hypothetical monopolist methodology reveals that clinker has a larger relevant market than hydraulic cement. However, using the EU's indicator of trade intensity puts hydraulic cement in front of clinker. This illustrates the fact that while hydraulic cement is currently more traded than clinker (relative to the amount produced), clinker has a higher potential for trade expansion due to its higher levels of homogeneity and lower trade costs.[29] Without measuring *potential* trade, the relatively lower clinker trade levels currently observed may obscure its true market size. Policymakers should therefore take this parameter into account when measuring carbon leakage risk.

Importance of product-level market definitions. The results of this paper's analysis reveal significant differences in the market definitions of each specific product. Differences are apparent in terms of the price increase needed for a significant market expansion and in terms of the specific countries included in each country's relevant market. The countries included in each product's relevant market reflect the specialization discussed above, but also the trade costs associated with reaching the EU's market. For instance, clinker is

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[27] See the article by an industry specialist on Project Blue, available at https://web.archive.org/web/20240525173158/https://projectblue.com/blue/news-analysis/525/why-could-steel-industry-de-carbonisation-be-long-and-difficult.

[28] The BF-BOF production route allows for a higher level of purification of iron ore than the EAF production route does. This means that it can produce higher-quality grades of steel from iron ore with low levels of purity (International Energy Agency, 2020).

[29] See the note prepared by PEC Consulting Group, available at https://pecconsultinggroup.com/grinding-plant-utilizing-imported-clinker/.

lighter and therefore easier and cheaper to transport than hydraulic cement.[30] This can also explain why this product has a larger relevant market at lower levels of a price increase.

The fact that results differ substantially by product is in line with the rest of the literature that highlights that aggregating products or sectors too much may create a bias in the measure of carbon leakage risk (Fischer & Fox, 2018). The policy implication of this finding is that all assessments of carbon leakage should be conducted at the lowest level of disaggregation possible. This can help to prioritize the products that are the most at risk. Additionally, studying products within a common value chain, like clinker and hydraulic cement, can help to highlight risks of reshuffling.[31] Identifying specific countries that produce the closest substitute products to the EU's can also help policymakers to strategically target these countries for partnerships aimed at fostering common climate standards and policies.

Impacts on exporters. One of the issues around carbon leakage is whether anti-leakage measures should be applied to all producers, only importers or only exporters (Ambec et al., 2024; Fischer & Fox, 2012). This stems from the fact that there may be legal challenges to implementing anti-leakage measures for exporters as they may be seen as export subsidies, which are outlawed by international trade law (Cameron & Baudry, 2023). The results indicate that for certain products, there may be minimal risk of competitiveness losses for exporters, as they are already absent from many countries' relevant markets.

EU producers of hydraulic cement and flat steel are not on any non-EU country's relevant market even when these countries increase their prices by 5 to 20%. A 50% price increase is required for the EU to appear in more than 50% of some countries' relevant market simulation outcomes. EU producers of clinker and long steel products appear to be in a few countries' relevant market at lower levels of a price increase.

Additionally, it is clear in the results with the 50% price increase that EU cement and clinker exporters do not operate on the same markets as EU steel exporters. In the cement sector, the countries that appear the most are on the African continent – with the addition of Myanmar and Australia for hydraulic cement. On the other hand, for steel, the USA, Canada, China, India and Colombia appear as important markets that EU producers can

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[30] See the note prepared by PEC Consulting Group, available at https://pecconsultinggroup.com/grinding-plant-utilizing-imported-clinker/

[31] Reshuffling refers to companies intentionally exporting their cleanest products to countries with stringent policies and their dirtiest products to other countries. This allows them to avoid true carbon reductions, and is a risk often highlighted in the literature (Böhringer et al., 2022; Grubb et al., 2022).

compete on. This seems to indicate that EU cement producers are only competitive on their own regional market, while for steel, they can be competitive globally – in the case of a 50% price increase in foreign countries.

The EU's CBAM will only cover products imported into the bloc, not those exported by its own producers. The results suggest that impacts on exporters may be fairly limited, as they are already not very competitive on many foreign markets. Targeting specific countries to establish bilateral climate standards and policies in markets that are the most relevant by product may be effective to alleviate impacts on exporters without resorting to distortionary measures such as export subsidies.

6.3 Limitations

Several limitations of this work need to be highlighted. First, the data available for the different steps in the analysis are sometimes limited both in terms of their quality and their range. There is a scope for improvement using more precise and comprehensive data that may be available in the future, namely for margin rates. Additionally, this analysis would have to be extended to many more sectors and products in order to be used in a policymaking context.

Second, because the margin rates that I use for all countries are based on the distribution from EU margin rates, they are entirely based on real market conditions. This may induce a bias since low observed margin rates would lead the hypothetical monopolistic test to show that the relevant market is very small, but could actually reflect an already competitive market and therefore induce a fallacy. The risk of this happening in the analysis is mitigated by the Monte Carlo simulation that is applied and the fact that I find that the relevant market is not only composed of the EU for all of the products covered. To fully measure and remove this bias, further research could compare observed margin rate values with margin rates derived from a counterfactual analysis where no competition is observed.

7 Conclusion

This paper has proposed a new approach to measure the risk of carbon leakage in the cement and steel sectors, looking in particular at the competitive market conditions for both of these heavy industries. Applying the hypothetical monopolist test to EU heavy industry producers, this study highlights significant variation in carbon leakage risks across clinker, cement, and flat and long steel products. This variation is driven by differences in homogeneity, trade costs, and regional specialization. Clinker consistently exhibits the largest relevant market, even at low levels of price increases, while steel products show significant market expansion only at higher thresholds of price increases. These findings emphasize the need for targeted, product-specific climate and trade policies to address carbon leakage effectively.

Future research could expand this study by incorporating more industrial sectors and products – this would bolster the policy relevance of the methodology proposed. On the data side, it would be particularly useful to include more granular and comprehensive data on margin rates. Exploring dynamic models that account for innovation and potential changes in trade and production patterns globally could also further refine estimates of carbon leakage risks. Finally, comparative studies across regions beyond the EU could inform about risks of carbon leakage in different jurisdictions and help countries to develop strategic partnerships on climate policies and standards.

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Appendix

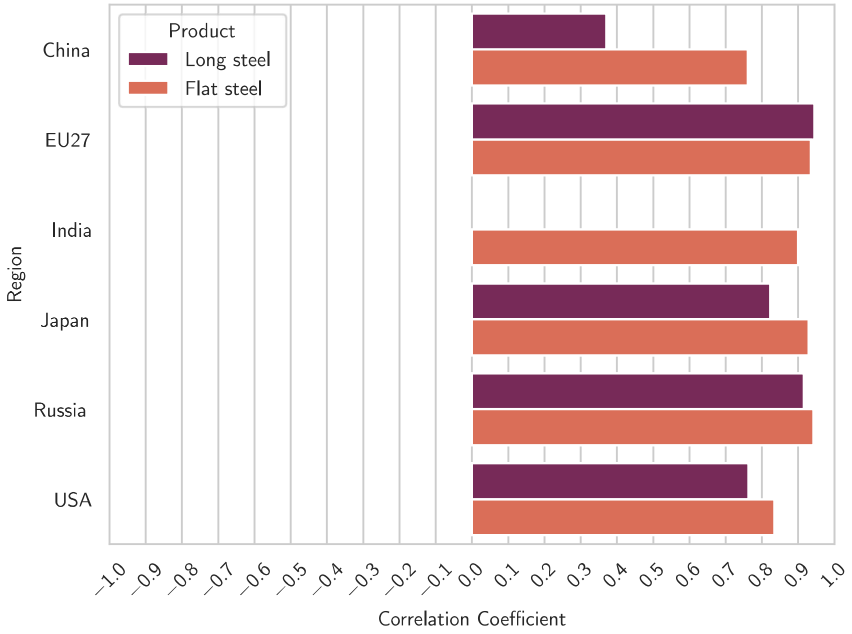
A Data

A.1 Table of products

HS code	HS description	Product
252310	Cement clinkers	Clinker
252321	Portland cement - White cement, whether or not artificially colored	Hydraulic cement
252329	Portland cement - other	Hydraulic cement
252330	Aluminous cement	Hydraulic cement
252390	Other hydraulic cements	Hydraulic cement
7208xx	Flat-rolled products of iron or nonalloy steel, of a width of 600 mm (23.6 in.) or more, hot-rolled, not clad, plated or coated	Flat steel products
7209xx	Flat-rolled products of iron or nonalloy steel, of a width of 600 mm (23.6 in.) or more, cold-rolled (cold-reduced), not clad, plated or coated	Flat steel products
7210xx	Flat-rolled products of iron or nonalloy steel, of a width of 600 mm (23.6 in.) or more, clad, plated or coated	Flat steel products
7211xx	Flat-rolled products of iron or nonalloy steel, of a width of less than 600 mm (23.6 in.), not clad, plated or coated	Flat steel products
7212xx	Flat-rolled products of iron or nonalloy steel, of a width of less than 600 mm (23.6 in.), clad, plated or coated	Flat steel products
7213xx	Bars and rods, hot-rolled, in irregularly wound coils, of iron or nonalloy steel (long products)	Long steel products
7214xx	Other bars and rods of iron or nonalloy steel, not further worked than forged, hot-rolled, hot-drawn or hot-extruded, but including those twisted after rolling	Long steel products
7215xx	Other bars and rods, of iron or nonalloy steel	Long steel products
7216xx	Angles, shapes and sections of iron or nonalloy steel	Long steel products
7217xx	Wire of iron or nonalloy steel	Long steel products

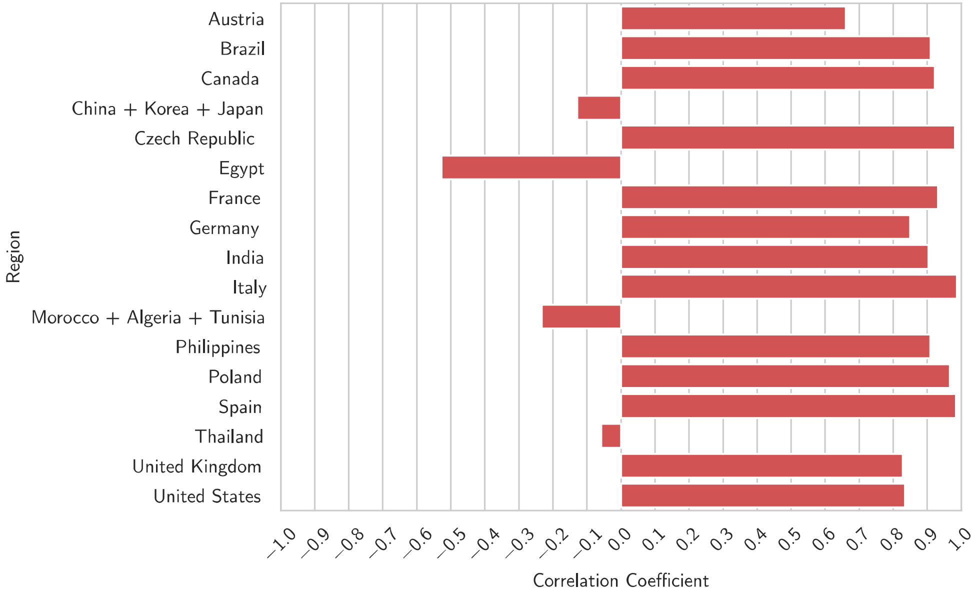
A.2 Steel price data verification

Figure 13: Correlation between computed steel price data and OECD steel price data



A.3 Clinker production data verification

Figure 14: Correlation between computed clinker production data and Global Concrete and Cement Association clinker production data



A.4 Comparison of trade elasticities of substitution

Table 3: Estimates of trade elasticities of substitution

Paper	**Sigma**	**S.E.**	**Original product**	**Attributed product**
Fontagné et al. (2019)	13.9688	-	HS 252310	Clinker
Fontagné et al. (2019)	9.417004	-	HS 252321	Hydraulic cement
Fontagné et al. (2019)	17.92119	-	HS 232529	Hydraulic cement
Fontagné et al. (2019)	15.33466	-	HS 232530	Hydraulic cement
Fontagné et al. (2019)	6.78148	-	HS 252390	Hydraulic cement
Fontagné et al. (2019)	9.927554	-	HS 720810	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720825	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720826	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720827	Flat steel
Fontagné et al. (2019)	7.054688	-	HS 720836	Flat steel
Fontagné et al. (2019)	3.850092	-	HS 720837	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720838	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720839	Flat steel
Fontagné et al. (2019)	11.00852	-	HS 720840	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720851	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720852	Flat steel
Fontagné et al. (2019)	14.54622	-	HS 720853	Flat steel
Fontagné et al. (2019)	13.17825	-	HS 720854	Flat steel
Fontagné et al. (2019)	9.927554	-	HS 720890	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720915	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720916	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720917	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720918	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720925	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720926	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720927	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720928	Flat steel
Fontagné et al. (2019)	12.5062	-	HS 720990	Flat steel
Fontagné et al. (2019)	8.44384	-	HS 721011	Flat steel
Fontagné et al. (2019)	7.285771	-	HS 721012	Flat steel
Fontagné et al. (2019)	8.44384	-	HS 721020	Flat steel
Fontagné et al. (2019)	8.44384	-	HS 721030	Flat steel
Fontagné et al. (2019)	12.46808	-	HS 721041	Flat steel
Fontagné et al. (2019)	6.586295	-	HS 721049	Flat steel
Fontagné et al. (2019)	8.373048	-	HS 721050	Flat steel
Fontagné et al. (2019)	6.50311	-	HS 721061	Flat steel
Fontagné et al. (2019)	8.44384	-	HS 721069	Flat steel
Fontagné et al. (2019)	9.446736	-	HS 721070	Flat steel
Fontagné et al. (2019)	8.44384	-	HS 721090	Flat steel
Fontagné et al. (2019)	6.062273	-	HS 721210	Flat steel
Fontagné et al. (2019)	6.062273	-	HS 721220	Flat steel
Fontagné et al. (2019)	5.871687	-	HS 721230	Flat steel
Fontagné et al. (2019)	6.652194	-	HS 721240	Flat steel
Fontagné et al. (2019)	5.662936	-	HS 721250	Flat steel
Fontagné et al. (2019)	6.062273	-	HS 721260	Flat steel
Fontagné et al. (2019)	26.66272	-	HS 721310	Long steel
Fontagné et al. (2019)	13.70141	-	HS 721320	Long steel
Fontagné et al. (2019)	8.350808	-	HS 721391	Long steel

Continued on next page

Table 3 continued from previous page

Paper	Sigma	S.E.	Original product	Attributed product
Fontagné et al. (2019)	5.801511	-	HS 721399	Long steel
Fontagné et al. (2019)	23.19176	-	HS 721410	Long steel
Fontagné et al. (2019)	15.07419	-	HS 721420	Long steel
Fontagné et al. (2019)	14.17237	-	HS 721430	Long steel
Fontagné et al. (2019)	7.690362	-	HS 721491	Long steel
Fontagné et al. (2019)	5.825302	-	HS 721499	Long steel
Fontagné et al. (2019)	19.23537	-	HS 721510	Long steel
Fontagné et al. (2019)	11.05093	-	HS 721550	Long steel
Fontagné et al. (2019)	8.167645	-	HS 721590	Long steel
Fontagné et al. (2019)	6.245874	-	HS 721610	Long steel
Fontagné et al. (2019)	6.942575	-	HS 721621	Long steel
Fontagné et al. (2019)	10.50129	-	HS 721622	Long steel
Fontagné et al. (2019)	13.52268	-	HS 721631	Long steel
Fontagné et al. (2019)	8.628777	-	HS 721632	Long steel
Fontagné et al. (2019)	6.433973	-	HS 721633	Long steel
Fontagné et al. (2019)	8.562211	-	HS 721640	Long steel
Fontagné et al. (2019)	8.704834	-	HS 721650	Long steel
Fontagné et al. (2019)	18.33108	-	HS 721661	Long steel
Fontagné et al. (2019)	10.55549	-	HS 721669	Long steel
Fontagné et al. (2019)	16.76702	-	HS 721691	Long steel
Fontagné et al. (2019)	10.81971	-	HS 721699	Long steel
Fontagné et al. (2019)	12.85082	-	HS 721710	Long steel
Fontagné et al. (2019)	7.412021	-	HS 721720	Long steel
Fontagné et al. (2019)	9.705378	-	HS 721730	Long steel
Fontagné et al. (2019)	8.853293	-	HS 721790	Long steel
Feenstra (1994)	4.21	0.94	Flat steel	Flat steel
Feenstra (1994)	3.59	0.35	Long steel	Long steel
Caliendo and Paro (2015)	7.99	2.53	Basic metals	Flat steel
Caliendo and Paro (2015)	7.99	2.53	Basic metals	Long steel
Caliendo and Paro (2015)	2.76	1.44	Non metallic minerals	Clinker
Caliendo and Paro (2015)	2.76	1.44	Non metallic minerals	Hydraulic cement
Fischer and Fox (2018)	6.1	-	Iron and Steel	Flat steel
Fischer and Fox (2018)	6.1	-	Iron and Steel	Long steel
Fischer and Fox (2018)	4.65	-	Iron and Steel and Ferroalloy Steel Products	Flat steel
Fischer and Fox (2018)	4.65	-	Iron and Steel and Ferroalloy Steel Products	Long steel
Fischer and Fox (2018)	3.02	-	Non metallic minerals	Clinker
Fischer and Fox (2018)	3.02	-	Non metallic minerals	Hydraulic cement
Fischer and Fox (2018)	0.36	-	Cement	Hydraulic cement
Ossa (2015)	2.16	0.065	SITC 673	Flat steel
Ossa (2015)	2.19	0.125	SITC 661	Hydraulic cement
Ossa (2015)	2.22	0.12	SITC 679	Long steel
Ossa (2015)	2.84	0.24	SITC 676	Long steel
Ossa (2015)	3.43	0.635	SITC 674	Flat steel
This paper	5.845	0.697	Hydraulic cement	Hydraulic cement
This paper	6.44	1.296	Clinker	Clinker
This paper	4.287	0.331	Long steel	Long steel
This paper	3.308	0.237	Flat steel	Flat steel

Note: “Original product” is the product categorization provided in the source paper. “Attributed product” is the product categorization attributed in this paper.

B Theory and model

B.1 Part one: the Hypothetical Monopolist Test

The hypothetical monopolist test determines whether it is *profitable* for a hypothetical monopolist controlling the production of good j and of its substitutes $i \in \Theta_j = \{1, ..., N'\}$ to increase the price of j by a small but significant amount - set by convention at $+5\%^{32}$. Formally, this means testing whether profits made by this hypothetical monopolist are greater before or after the price increase. If they are greater before, then the relevant market has been identified.[33]

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

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

By definition, we have the following own- and cross-price elasticity formulations:

$$\varepsilon_{jj} = \frac{\Delta q_j / q_j}{\Delta p_j / p_j} \quad \Leftrightarrow \quad \Delta q_j = \varepsilon_{jj} \frac{\Delta p_j}{p_j} q_j$$

$$\varepsilon_{ij} = \frac{\Delta q_i / q_i}{\Delta p_j / p_j} \quad \Leftrightarrow \quad \Delta q_i = \varepsilon_{ij} \frac{\Delta p_j}{p_j} q_i$$

p_j is the good j's unit price and q_j is the quantity produced. The quantities of j and i that are sold both before and after the price increase are respectively given by:

$$q_j + \Delta q_j = q_j + (\varepsilon_{jj} x q_j) = q_j(1 + \varepsilon_{jj} x)$$

$$q_i + \Delta q_i = q_i + (-\varepsilon_{ij} x q_i) = q_i(1 + \varepsilon_{ij} x)$$

With $x = \frac{\Delta p_j}{p_j}$. Pre- and post-price increase profits are defined as follows:

$$\Pi^{pre}_{j+\Theta_j} = (p_j - c_j)q_j + \sum_{j \neq i}^{N'} (p_i - c_i)q_i$$

$$\Pi^{post}_{j+\Theta_j} = (p_j(1+x) - c_j)(q_j + \Delta q_j) + \sum_{j \neq i}^{N'} (p_i - c_i)(q_i + \Delta q_i)$$

---

[33] All equations in this appendix are numbered as in the main text so they can easily be matched up.

I substitute Δq_j and Δq_i in the definition of post-price increase profits:

$$\Pi^{post}_{j+\Theta_j} = (p_j + p_j x - c_j)(q_j(1+\varepsilon_{jj}x)) + \sum_{j\neq i}^{N'}(p_i - c_i)q_i(1+\varepsilon_{ij}x)$$

c_j is the good j's ex ante unit cost and x is the percentage price increase imposed on j by the hypothetical monopolist, which is set at 5% by convention.

This gives us the following value for the change in profit:

$$\Delta\Pi_{j+\Theta_j} = \Pi^{post}_{j+\Theta_j} - \Pi^{pre}_{j+\Theta_j}$$

$$\begin{aligned}\Leftrightarrow \Delta\Pi_{j+\Theta_j} =& (p_j + p_j x - c_j)(q_j(1+\varepsilon_{jj}x)) + \sum_{j\neq i}^{N'}(p_i - c_i)(q_i(1+\varepsilon_{ij}x)) \\ & - (p_j - c_j)q_j - \sum_{j\neq i}^{N'}(p_i - c_i)q_i\end{aligned}$$

$$\begin{aligned}\Leftrightarrow \Delta\Pi_{j+\Theta_j} =& (p_j - c_j)q_j\varepsilon_{jj}x + xp_jq_j(1+\varepsilon_{jj}x) \\ & + \sum_{j\neq i}^{N'}(p_i - c_i)q_i\varepsilon_{ij}x\end{aligned}$$

I divide and multiply by prices p_j and p_i to make margin rates μ and turnover v apparent:

$$\Delta\Pi_{j+\Theta_j} = \varepsilon_{jj}x * \underbrace{\frac{p_j - c_j}{p_j}}_{\mu_j} * \overbrace{p_jq_j}^{v_j} + x * \overbrace{p_jq_j}^{v_j} * (1+\varepsilon_{jj}x)$$

$$+ \sum_{j\neq i}^{N'} \underbrace{\frac{p_i - c_i}{p_i}}_{\mu_i} * \overbrace{p_iq_i}^{v_i} * \varepsilon_{ij}x$$

Adding the condition that $\Delta\Pi_{j+\Theta_j} > 0$:

$$\Delta\Pi_{j+\Theta_j} > 0$$

$$\Leftrightarrow \varepsilon_{jj} x \mu_j v_j + x v_j (1 + \varepsilon_{jj} x) + \sum_{j \neq i}^{N'} \mu_i v_i \varepsilon_{ij} x > 0$$

Finally, factorizing by ε_{jj} and dividing by x yields the following condition, which is used as the empirical application of the hypothetical monopolist test:

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

B.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 maximizing agent is a downstream producer buying industrial goods from an upstream consumer 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 $j \in \{1, ..., N\}$ buying from all other countries, the top level of this production function, specifying the substitution between labor and primary industrial goods, 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 industrial good has N different varieties, one for each country/upstream producer in the world. As such, country j has access to its own variety, as well as varieties from all other countries $i \in \{1, ..., N\}$. A variety is therefore defined as a good exported from country i and imported by country j. The lower level of the production function for these different varieties is defined as follows:

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

Where σ is the CES elasticity of substitution between different varieties of a good and m_{ij} is the quantity of each variety that is used in physical units. The downstream producer's cost minimization problem is defined as:

$$\begin{aligned} \min \quad & w_j L_j + P_j M_j \\ \text{s.t.} \quad & L_j^{\alpha} \left[\left(\sum_{i=1}^{N} m_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \right]^{1-\alpha} = Y_j \end{aligned}$$

Where w_j are wages and P_j is the price index in country j.

Solving for this gives the following minimized demand function for the aggregate industrial good M_j:

$$M_j^* = Y_j \left(\frac{\alpha}{1-\alpha} \right)^{-\alpha} P_j^{-\alpha} w_j^{\alpha}$$

Next, I minimize the cost of all varieties subject to the production function to obtain the aggregate industrial good, where M_j^* is the targeted amount of the aggregate industrial good obtained in the previous equation:

$$\begin{aligned} \min_{(m_{ij},\ldots,m_{Nj})} \quad & \sum_{i=1}^{N} p_{ij} m_{ij} \\ \text{s.t.} \quad & \left(\sum_{i=1}^{N} m_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} = M_j^* \end{aligned}$$

Minimizing for a single variety $m_{ij'}$ gives the following first order condition:

$$p_{ij'} - \lambda \left(\sum_{i=1}^{N} m_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}-1} m_{ij'}^{\frac{\sigma-1}{\sigma}-1} = 0$$

This implies:

$$m_{ij'} = p_{ij'}^{-\sigma} \lambda^{\sigma} M_j^{*\,-\alpha}$$

Substituting this back into the constraint yields:

$$\lambda^{\sigma} M_j^{*\,-\alpha} = M_j^* \left(\sum_{i=1}^{N} p_{ij'}^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}}$$

Substituting this back into the above expression of $m_{ij'}$ and taking the more generic case for m_{ij} gives us the demand for a good m_{ij} conditional on consumption of the aggregate industrial good M_j^* and price p_{ij}:

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

To get to the price index, we start from:

$$\underbrace{\sum_{i=1}^{i} p_{ij} m_{ij}}_{\substack{\text{sum of demand for all} \\ \text{varieties of the industrial good} \\ \text{in country } j}} \quad = \quad \overbrace{P_j M_j^*}^{\substack{\text{aggregate demand for} \\ \text{the industrial good} \\ \text{in country } j}}$$

Substituting equation (6) into this yields the following price index P_j, which coincides with the price index found in the standard consumer maximization-based gravity model:

$$P_j = \left(\sum_{i=1}^{N} p_{ij}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

Given this expression of the price index, the conditional expression of m_{ij} can be rewritten:

$$m_{ij} = M_j^* \frac{p_{ij}^{-\sigma}}{P_j^{-\sigma}}$$

Assuming iceberg transport costs defined as $p_{ij} = p_i t_{ij}$ with t_{ij} transport costs between i and j and p_i the factory-gate price in country i, the price index can be expressed as:

$$P_j = \left(\sum_{i=1}^{N} (p_i t_{ij})^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

From this we can get the trade flow X_{ij} of a good from country i to country j:

$$X_{ij} = p_{ij} m_{ij} = p_{ij} \frac{(p_{ij})^{-\sigma}}{P_j^{-\sigma}} M_j^*$$

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

This is the theoretical equation from which I derive the gravity model used in estimations. Finally, market clearing is imposed for goods from each origin, with O_i country i's production of the good:

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

Following Yotov et al. (2016), I define world output $O = \sum_{i=1}^{N} O_i$ and divide (8) by O:

$$p_i^{1-\sigma} = \frac{O_i/O}{\sum_{j=1}^{N} \frac{t_{ij}^{1-\sigma}}{P_j^{-\sigma}} \frac{M_j^*}{O}}$$

Following Anderson and van Wincoop (2003) and Yotov et al. (2016), the structural term Ω_i is defined as $\Omega_i = \left(\sum_{i=1}^{N} \frac{t_{ij}^{1-\sigma}}{P_j^{-\sigma}} \frac{M_j^*}{O} \right)^{\frac{1}{1-\sigma}}$. It can be substituted back into the previous equation:

$$p_i^{1-\sigma} = \frac{O_i/O}{\Omega_i^{1-\sigma}}$$

Substituting this into the equations respectively defining X_{ij} and P_j yields:

$$X_{ij} = \frac{O_i M_j^*}{O} \left(\frac{t_{ij}}{\Omega_i P_j^{\frac{-\sigma}{1-\sigma}}} \right)^{1-\sigma}$$

$$P_j^{1-\sigma} = \sum_{i=1}^{N} \left(\frac{t_{ij}}{\Omega_i} \right)^{1-\sigma} \frac{O_i}{O}$$

I suppose that transport costs are defined as in equation (9) below, with δ_j importer j's distance elasticity and $dist_{ij}$ the geographical distance between countries i and j:

$$t_{ij} = \delta_j dist_{ij} \tag{9}$$

Log-linearizing the expression of X_{ij} above, adding distance as defined in equation (9) and a time index t yields the gravity equation used for estimation:

$$\begin{aligned}\log X_{ij,t} =& \log M^*_{j,t} + \log O_{i,t} - \log O_t + (1-\sigma)\log dist_{ij,t} + (1-\sigma)\log \delta_{j,t} \\ &- (1-\sigma)\log \Omega_{i,t} - \sigma \log P_{j,t} + \epsilon_{ij,t}\end{aligned}$$

I use a PPML estimator with importer-year and exporter-year fixed effects, $\pi_{i,t}$ and $\chi_{j,t}$ respectively. I estimate the following gravity equation, in which the terms $\log M^*_{j,t}$, $\log O_{i,t}$, $(1-\sigma)\log \delta_{j,t}$, $(1-\sigma)\log \Omega_{i,t}$, and $\sigma \log P_{j,t}$ are captured by the fixed effects:

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

Own- and cross-price elasticities. Going back to the price index defined above, and substituting it into the minimized demand function for the aggregate industrial good M^*_j:

$$M^*_j = Y_j \left(\frac{\alpha}{1-\alpha}\right)^{-\alpha} \left[\left(\sum_{i=1}^{N} p_{ij}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}\right]^{-\alpha} w_j^{\alpha}$$

Substituting this into the expression of demand for a variety ij:

$$m_{ij} = p_{ij}^{-\sigma} Y_j \left(\frac{\alpha}{1-\alpha}\right)^{-\alpha} \left[\left(\sum_{i=1}^{N} p_{ij}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}\right]^{-\alpha} w_j^{\alpha} \left(\sum_{i=1}^{N} p_{ij}^{1-\sigma}\right)^{\frac{\sigma}{1-\sigma}}$$

$$m_{ij} = \left(\frac{\alpha}{1-\alpha}\right)^{-\alpha} w_j^{\alpha} Y_j \frac{p_{ij}^{-\sigma}}{(\sum_{i=1}^{N} p_{ij}^{1-\sigma})^{\frac{\alpha-\sigma}{1-\sigma}}}$$

From this we can derive the expressions for country j's own- and cross-price elasticities, respectively ε_{jj} and ε_{ij}, defined as:

$$\varepsilon_{jj} = \frac{\partial m_{jj}}{\partial p_{jj}} \frac{p_{jj}}{m_{jj}} \quad \text{and} \quad \varepsilon_{ij} = \frac{\partial m_{ij}}{\partial p_{jj}} \frac{p_{jj}}{m_{ij}}$$

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

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

C Additional regression results

C.1 Gravity regression with cultural distance controls

Table 4: Gravity regression results with cultural distance controls

	(1) Hydraulic cement	(2) Clinker	(3) Long steel	(4) Flat steel
Log distance	-4.759***	-5.898***	-2.988***	-2.151***
	(0.316)	(0.547)	(0.322)	(0.144)
RTA	-2.371***	-4.423***	-1.683***	-1.658***
	(0.653)	(0.906)	(0.533)	(0.275)
Common language	-1.245	-1.864***	-0.354	-0.531
	(0.823)	(0.712)	(0.565)	(0.554)
Contiguous	-2.885***	-4.670***	-2.229***	-1.833***
	(0.682)	(0.689)	(0.506)	(0.348)
Former colonial tie	-0.210	2.054***	1.344*	2.207***
	(0.596)	(0.677)	(0.790)	(0.557)
Observations	22491	7603	18031	17486
Pseudo R^2	0.99	0.99	0.99	0.97
Fixed effects:				
Exporter-year	Yes	Yes	Yes	Yes
Importer-year	Yes	Yes	Yes	Yes

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