SHIPPING DEMAND SCENARIOS USING ESTIMATED ELASTICITIES

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ABSTRACT

We incorporate qualitative assumptions arising from stylised trade and transportation facts together with quantitative trade and transportation output to derive: a) Projections of future intermediate/final consumption of selected groups of commodities carried by sea, under different assumptions regarding target temperature thresholds; b) Assess the sensitivity of these projections with respect to known determinants of maritime transportation costs such as proximity, taxation, quality. Alternative methods can be applied to project future trade demand based on differing patterns of production and consumption. These can be underpinned by examining the relationships between economic development and material flow indicators, as well economic projections aligned with different decarbonisation scenarios. For key commodities such as iron ore, which are linked to a carbon intensive manufacturing process, the choice of decarbonisation scenario can have significant implications for future trade patterns. The results of such analysis for this commodity can be compared against projections informed by econometric analysis, demonstrating the impact of methodological differences and assumptions on how the drivers for trade may manifest. These projections can be used to improve our understanding regarding the implications of climate change policies to international shipping.

Keywords: econometrics, scenario, trade, costs, decarbonisation, iron ore,

1. INTRODUCTION

Global trade has increased over 30 fold, by volume, since 1950 (WTO, 2014). This growth in world trade represents not just a change in quantitative terms, but also changes to the fundamental structure of the system which underpins it with greater interconnectedness along supply chains and cross-border investment flows (Soubbotina and Sherman, 2000). Trade is hugely important for global economic development and although when viewed at a global scale, the relationship between trade and economic growth appears incontestable, there are many factors related to trade that can have a significant impact on economic growth. Rodriguez (2007). These factors are many and varied, including investment, technology transmission and a stabilisation of macro-economic policies (Wacziarg 2001), openness to trade (Berg and Krueger 2003) and geography (Hummels 2001, Feyer 2009). Whilst such studies are informative to determine elements which have impacted on trade in the past, they cannot (nor do they claim to) take into account future system as a consequence of changes to the dynamics of supply and demand where there is no recent analogue. Our particular interest in this topic relates to the extent to which climate change will impact on trade. The recent AR5 report from the IPCC cautions that without significant levels of emission reductions, climate change impacts will be significant. From the point of view of the shipping sector, understanding how climate change mitigation, adaptation and impacts will affect trade is crucial. Given the range of potential determinants seeking to generate a definitive projection which reflects such components is unrealistic, and instead the generation of contrasting scenarios which explore how important determinants of trade may manifest is a more meaningful exercise.

1.1 AIM AND OBJECTIVES

This paper focuses on trade scenarios developed to explore trade in changing climates. Section 2 outlines the approach to developing trade scenarios adopted within the project, with emphasis on two different methods used to identify elements which impact upon trade: an econometric approach which applies a statistical analysis to trade patterns to derive robust relationships between criteria such as transport distance or transport cost and an approach based on material flows. Econometric approaches offer a level of completeness and certainty (whilst reducing the potential for bias or arbitration), but can be dependent on the quality of supporting data (such as reliable costs). Furthermore, whilst such a method can be applied to distinct commodities, such approaches are generally applied to a broad range of commodities. Since, however, the demand for trade depends on factors wider than the markets in which they operate, the paper supplements the econometric assessment with scenarios of traded quantities based on national level projections on both the domestic demand and production for key commodities, which are informed by SSP projections on economic development. This is undertaken for a specific commodity, iron ore as it is a significant contributor to global seaborne trade, reflecting approximately 10% of global seaborne trade (in terms of tonnage) over the past decade. Furthermore given its dependence on coal, significant modifications are envisioned in allowing the steel sector to meet its climate change obligations under a cumulative emission budget. In summary, this paper seeks to develop alternative visions of trade in changing climates, using both established and bespoke methods, with iron ore chosen as a case study for the latter.

2. THE SHIPPING IN CHANGING CLIMATE TRADE SCENARIOS

Scenarios are essentially a description of alternative futures which may be qualitative, quantitative or a combination of the two. The development and analysis of scenarios, through a scenario process, provides the opportunity for structured yet creative thinking about the future when considering complex systems (Borjeson et al. 2006). The trade scenarios developed within the Shipping in Changing Climate (SCC) project essentially compare and contrast international trade futures for greater and lesser levels of climate change mitigation. Characterised as 2°C and 4°C scenarios, a 2°C scenario is set within a world where there are greater levels of mitigation and fewer climate change impacts as a consequence. By contrast, a 4°C world suggests that emissions of greenhouse gases are higher, with more significant impacts from climate change, and a greater emphasis on adaptation.

The SCC trade scenarios are framed by cumulative emissions budgets associated with 2°C and 4°C. The quantitative budgets for global shipping are derived through use of the RCP's developed for the IPCC AR5 (Pachauri et al. 2014). The 2°C scenarios are bounded by the emission pathways of RCP 2.4, and the 4°C scenarios by RCP 8.6. Each of the trade scenarios consists of a qualitative narrative, and quantified trade flows for key commodities in 2050. The visions of world trade developed in each of the SCC scenarios, are informed by the Shared Socio-economic Pathways (SSPs) also developed for AR5 (van Vuuren et al., 2014). Answering the call (O'Neill et al., 2014) for the SSP's to be used by researchers to inform their exploration of the future, the SCC scenarios interpret both the qualitative narratives and quantitative indicators of the SSPs as assumptions to quantify future trade. The SSPs are presented as a means of framing discussion around climate change and describe different socio-economic reference projections which encompass the socio-economic challenges to climate change mitigation and adaption (O'Neill et al., 2014; van Vuuren et al., 2014). SSP 1 envisions low challenges to mitigation and adaptation and is considered a sustainable pathway. SSP 2 reflects a "middle of the road" framing with moderate challenges to both. SSP 3 projects a more fragmented world with both mitigation and adaptation highly challenging. SSP 4 represents greater inequality where adaptation challenges are to fore. SSP5 continues established trends dominated by the challenges to mitigation.

Such framing informs the qualitative narratives that underpin each SSP, expressed in 5 broad categories: human development, technology, lifestyles, environment and natural resources, policies and institutions. This is complimented by quantification of core socio-economic criteria: population, GDP and urbanisation. These narratives and indicators are intended to provide consistent assumption which can be used in other work such as integrated assessment modelling. The drivers of trade are numerous and complex, which makes projections of trade under contrasting RCP and SSP similarly tricky. In order to project future trade, the project makes use of 2 approaches: an econometric approach which applies a statistical analysis to trade patterns to derive robust relationships between criteria such as transport distance or transport cost and an approach based on material flows. Used together, they allow more informed projections through the capacity to include statistically valid relationships but also reflect dramatic or specific changes due to both specific policies or physical constraints.

2.1 A FOCUS ON THE ORE TRADE

For the purposes of this paper, we present a case study of future trade in iron ore, chosen because of the significant quantities traded by sea, and the interactions between the energy and emissions intensive steel sector, and climate change mitigation policies. Since 1980, the quantity of crude steel produced globally has more than doubled, with most of this increase occurring after 2000, following a period of expansionist industrialisation, and a resultant increase in Chinese steel output (Worldsteel, 2014). The quantity of traded ore increased by approximately 330% over the same period, as domestic production decreased in regions such as Europe and the output of mines in regions such as china could not meet demand. Since 2000, production in key regions such as Australia and Brazil has grown at a comparable rate to the increase in Chinese steel production. By 2010 approximately half of global steel was produced in China, with iron ore accounting for approximately 10% of total seaborne tonnage the same year. Between 1993 and 2013, the contribution of exports of ore from Australia and Brazil to China to total seaborne trade increased from 8 to 50% (MSI, 2014).

2.2. ECONOMETRIC ANALYSIS

The econometric analysis consists of estimating two reduced form relationships linking exports and transport costs to their determinants and then, following Hummels (2001), recovering the implicit relationship between transport costs and exports. For all estimations, fixed effects ordinary least squares regression is employed, together with clustered standard errors at the country pair level (Wooldridge 2002).

The theoretically derived reduced form gravity equation is:

$$\ln X_{ijkt} = \ln A_{ijkt} - \sigma_k \ln \tau^{a}_{ijkt} - (\sigma_k - 1) \ln B_{ij} + \epsilon_{ijkt}$$

Equation (1)

where the elasticity of exports with respect to advalorem transport costs τ on a specific commodity k is σ_k and with respect to all other barriers B_{ij} such as Language, Contiguity and Regional Trade Agreements, 1-σ_k . These elasticities are obtained from variation in the data that is ijk triplet or specific origin destination ij pair. Thus all other sources of variation that could “pollute” the estimates of σ, 1-σ can be absorbed using a vector of origin, destination, and commodity fixed effects, A_{ijk}. Extending the above relationship to accommodate more than one time period, time fixed effects are also employed.

The transport cost equation based on Hummels (2001) is assumed to take the following form:

$$\ln \bar{\tau}_{ijkt} = A_{ijkt} + \delta_{1,k} \ln \mathrm{distance}_{ij} + \delta_{2,k} \ln \frac{\mathrm{weight}_{ijkt}}{\mathrm{value}_{ijkt}} + \xi_{ijkt}$$

Equation (2)

The weight_{ijkt} /value_{ijkt} is a ratio of weight-to-value for good k when shipped from i to j and captures quality characteristics of the good transported. Thus higher values of the ratio imply heavier low valued goods are transported and vice versa. One expects to observe that high weight-to-value items tend to be more expensive to transport as greater weight and bulk of a commodity that has the same value as a lighter, less voluminous commodity, will require greater stowage capacity and fuel to transport to a particular destination (Hummels 2007). The vector of trade costs consists of a set of observable and unobservable barriers, and transport costs fall into the latter subset commonly in the literature (Combes, Lafourcade & Mayer 2005). In this regard, the practice is to express down the reduced form of the value of exports equation as:

$$\ln X_{ijkt} = \ln A_{ijkt} - \sigma_k \delta_{1,k} \ln \mathrm{distance}_{ij} - (\sigma_k - 1) \ln B_{ij} + \epsilon_{ijkt}$$

Equation (3)

Within this equation the weight-to-value ratio is omitted due to endogeneity arising from reverse causal effects with the dependent variable that would lead to biased estimates, as both exports and ratio are a function of price and quantity shipped. In this particular specification distance, used as a proxy for transportation costs in the extant bibliography for lack of better measurement, enters with an elasticity of $\sigma_k\delta_{1,k}$. The purpose of the applied econometrician thus becomes to identify separately the impacts of σ_k and $\delta_{1,k}$. Applying these two relationships to the same sample interchangeably allows a separation from the joint impact the parameters and permits inference regarding i) the elasticity of exports with respect to advalorem transport costs, ii) the technological effect of distance on transportation, and ultimately on exports. The empirical strategy thus consists of the following steps.

1. Estimate equation 2, and obtain $\delta_{1,k.}$
2. Estimate relationship 3, recover and comment on the obtained $\sigma_k\delta_{1,k}$.
3. Infer the individual impacts σ_k, $\delta_{1,k..}$
4. Based on these results construct predicted values of σ_κ.

In order to identify the impact of criteria such as transport distance and costs on trade, ordinary least squares (OLS) regression analysis was applied to trade data which of country to country flows. The dataset employed is the OECD Maritime Transport Costs which contains observations of quantity transported by sea, and the associated freight, per unit and advalorem transport costs. The dataset spans 146 exporting, 41 importing countries which trade goods aggregated at the 6 digit Harmonised System (HS) classification of goods across the 1991-2007 period using four particular modes of transport: clean and dirty bulk carriers, tankers and containers. Zero flows are not recorded in the dataset. The dataset is embellished with cultural and geographical dummies and geodesic capital distance from the CEPII dataset. The dataset consists of a range of digit HS commodities that are traded amongst countries. Thus each of the 49 NST/R commodity categories consist of a unique subset of 6 digit HS commodities. The NST/R commodity categories that correspond to a group of iron ore commodities that we are concerned with are as follows:

Table 1: NST/R Commodities associated with Iron Ore

41	Iron ore
45	Non-ferrous ores and waste
46	Iron and steel waste and blast furnace dust
52	Semi-finished rolled steel products
53	Bars, sections, wire rod, railway and tramway track construction material of iron or steel
54	Steel sheets, plates, hoop and strip
55	Tubes, pipes, iron and steel castings and forgings

The OECD Maritime Transport Costs dataset, as the name implies, consists of observations of flows traded by sea. To this end, two distance variables are constructed from a grid[1] containing all possible distances from country capitals to their principal ports and then to their trading partners' principal ports and ultimately capitals. One is the minimal distance from capital to capital via principal ports. The other is the average distance from capital to capital via all principal ports. Since the minimum and average distance results were not statistically significantly different to each other, the analysis presents the outcomes for the minimum distance case. The dataset comes with two caveats. First maritime transport costs are observed for landlocked countries. In such situations, for the two distance variables, observations are constructed by using the closest principal port to the landlocked country's capital. Secondly, EU15 countries are represented as one country, thus losing the heterogeneity across individual member countries. The capital of the EU15 region is exogenously set to Brussels and the principal port to Rotterdam. At present, it is unclear what effect this has on the results.

For all estimations, unless otherwise specified, the sample is cleared of outliers which have been removed by dropping all flagged observations and observations which correspond to studentised residuals greater than 2.5. Standard errors are clustered at the country pair level, to allow for shocks affecting trade flows within commodities to differ across country pairs. Exporter(importer)-commodity-year fixed effects are employed. Commodity group “41 Iron ore” was estimated using exporter, importer, commodity, year fixed effects in a sample including outliers due to the low number of observations for the period. Commodity group “52 Semi-finished rolled steel products” was estimated using exporter-commodity, importer-commodity, year fixed effects in the aforementioned robust sample.

2.3 MATERIAL FLOW SCENARIOS

The production of steel consumes ore as a fundamental feedstock. In order to project future trade of ore commodities, it is necessary to project future demand for steel. This is achieved by estimating the future trends in the steel intensity of GDP (measured in tonnes of steel/PPP M$). For each steel producing county, historical

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trends in the steel intensity of GDP are estimated based on data on steel production (Worldsteel, 2014), GDP (James et al., 2012) and population (IMF, 2014). In order to maintain compatibility with the data contained within the SSPs, GDP estimates in terms of purchasing parity power (PPP) expressed in 2005$ international dollars are utilised. Purchasing power parity seeks to normalise estimates of GDP in terms of both the relative value of different currencies but also the extent to which the same "basket" of goods requires different values of currencies. Developing countries such as China with an industry expanding from a small base will demonstrate a different shape to regions with more established industries. Figures 1 and 2 below contrast the trend for China and Germany.

For each steel producing country (117, based on worldsteel 1980-2014), establishing the trends between these two variables (Per capita GDP and the ore intensity of GDP) allows economic and population estimates in different SSPs to be used to project future steel production. For the purposes of this exercise, two SSP are chosen, SSP 1 and SSP 2, considered to reflect a sustainable and "mixed" pathway. For countries such as Germany with an apparent correlation, the relations can be used readily whereas regions such as China require identifying analogues between their future SSP projections (in terms of GDP) and past developments in both GDP and population in other regions. The extent to which the steel intensity will change forms a part of the scenario narrative.

Once steel use has been estimated for each country, it is converted into ore demand based on projections of technological mix between steel production methods, such as the uptake of electric arc furnaces (which consumes iron scrap instead of ore) or direct reduction steel production. Data on the ore intensity of different steel production methods is taken from Morfeldt et al. (2014), based on the average iron content of ore. Technically the demand for ore is agnostic as to whether the sector meets a cumulative emissions budget as the same steel production technology may be applied with or without fossil inputs. In order to reflect a more radical departure, a modification to the SSP1 scenario is included whereby decarbonisation is achieved by penetration of electrically produced steel, under the assumption that the grid has decarbonised or dedicated renewable electricity is available. This is based on studies such as Bellevrat and Menanteau (2009) which state that under an approximate 2 °C scenario (presented as being consistent with 450 CO_2 ppm), by 2050 90% of global steel production to be satisfied by some form of zero carbon steel production method.

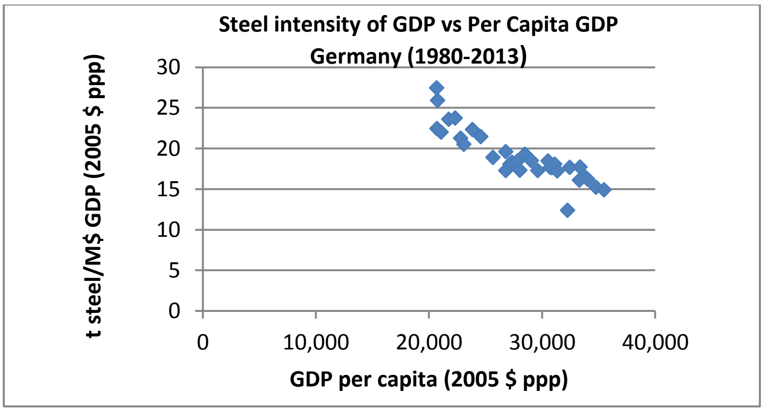

Figure 1: Comparison of steel intensity of Chinese GDP with per capita GDP.

Once domestic ore consumption is estimated it can be compared against domestic production in each country. Within each producing country recent trends in the level of production (Wordsteel, 2014b) are continued until reserves are depleted (USG, 2014, Mohr et al., 2014) where possible depletion time consistent with published in Yellishetty et al. (2010) are generated (albeit from a different start date). For some countries (such as China) this includes an assumption on when production will peak. Within each region the amount of domestically produced ore available for steel production is determined by annual production estimates from which the quantity exported is subtracted. The disparity between domestically available ore (after subtracting exports) and ore demand of steel reflects the import demand for ore. For each year the proportion of ore exports (as a % of production) for each main producer is curtailed to ensure that overall export demand does not exceed import demand. For each main steel producer the ratio between overall and seaborne trade, based on data from

(Wordsteel, 2014b) and MSI (2014). By way of example, the main assumptions for both scenarios based on differing SSPs are summarised in table 2 below.

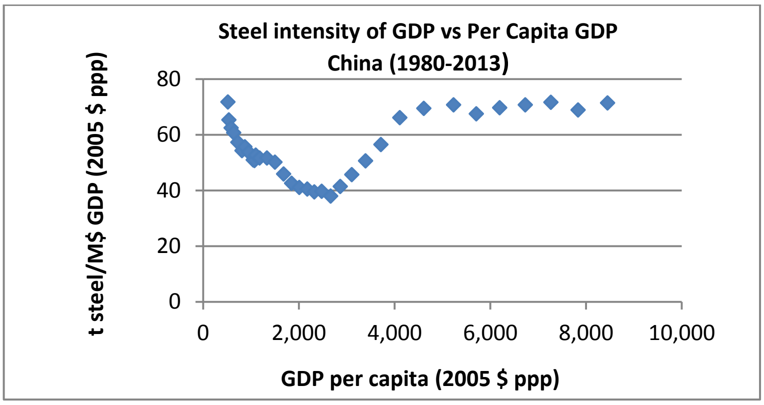

Figure 2: Comparison of steel intensity of Chinese GDP with per capita GDP.

Table 2:Summary of main scenario assumptions.

	SSP 1	SSP 2
Steel intensity of GDP	Decreases in most countries. By 2050 developing regions such as China reach comparable level to developed regions which are not significant steel producers. Regions such as India do not replicate the growth of China. Both these countries reflect developing regions undergoing industrialisation.	Decreases in most countries. Developing regions such reach comparable levels to developed regions which are significant steel producers. E.g. China assumed to reduce its steel intensity of GDP at a similar rate to Taiwan (post 2000) as its GDP per capita is projected to grow at a comparable rate. Some developing regions with a stable trend in intensity maintain it out to 2050.
Technology	Continued growth in penetration of electric steel production. By 2050 approximately half of global steel production satisfied by electric furnaces. Alternatively under a 2°C scenario by 2050 >80% of steel is produced through electric arc technology.	As with SSP1 but the proportion of Chinese steel produced through an electric arc furnace reduces with increasing GDP. By 2050 approximately 40% of global steel production is supported by electric steel.
Ore Production	Recent trends in production in each country until depletion. Countries such as Brazil and Australia remain most important exporters. Chinese ore production to peak in the 2020s and decline by same rate, maintaining comparable depletion time to Morfeldt et al. (2014). Regions with good quality ore increase production (e.g. Western Africa increases production) and progress into the export market. India re-enters export market.	

3. RESULTS

3.1 ECONOMETRIC RESULTS

Table 3 exhibits the sensitivity of net advalorem transport costs to changes in their determinants that vary across importers-exports, product groups and time. The first column lists the commodity category, followed by the coefficients on the minimum distance, weight/value ratio and respective standard errors. The table concludes with the measure of goodness of fit and number of observations for the exporter-importer-year triplet within each NST/R group. All results are significant at the 1% level. It is inferred that a 10% increase in distance raises the net advalorem transport costs of trading iron ore by 3.4%. Equivalently a 10% increase in the “bulkiness” of iron ore in the cargo hold increases transport costs by 3.7%. On average across the NST/R commodities of iron ore and its derivatives these estimates are representative. Table 4 illustrates the results for the export equation. Coefficients for binary controls such as contiguity, language, colony and regional trade agreements that were incorporated in the estimation are excluded herein for brevity of the exposition. We can infer that in this estimation a 10% increase in distance decreases exports of iron ore by 18.4%, around 10% on average for all other iron-ore related derivatives.

Table 3: Dependent Variable: Net advalorem transport costs

NST	Min. Dist	St. Error (Min Dist.)	weight/value	St. Error (Weight/Value)	R^2	N
41	0.34***	0.13	0.37***	0.08	0.42	847
45	0.22***	0.08	0.59***	0.06	0.97	8,941
46	N/A	N/A	N/A	N/A	N/A	N/A
52	0.36***	0.08	0.39***	0.05	0.61	848
53	0.32***	0.04	0.49***	0.02	0.9	30,154
54	0.4***	0.05	0.56***	0.03	0.86	14,989
55	0.34***	0.05	0.59***	0.02	0.89	34,917

Table 4 illustrates the results for the export equation. Coefficients for binary controls such as contiguity, language, colony and regional trade agreements that were incorporated in the estimation are excluded herein for brevity of the exposition. We can infer that in this estimation a 10% increase in distance decreases exports of iron ore by 18.4%, around 10% on average for all other iron-ore related derivatives. The elasticities of exports with respect to distance reported in table 3 contain information about transportation inter alia, since this represents a reduced form estimation of exports impacts from transport costs’ determinants. Because the remoteness of a country which is captured by the distance variable, can affect exports through channels other than transport costs such as information, we follow Hummels (2001) to derive the elasticity of exports solely with respect to advalorem transport costs. This is obtained by dividing the export elasticities of table 5 by the corresponding elasticities of transport costs with respect to distance of table 3.

Table 4: Dependent Variable: Log value of exports

NST/R	Min. Dist	St. Error	R2	N
41	-1.84***	0.54	0.77	847
45	-0.85***	0.33	0.91	8,941
46	N/A	N/A	N/A	N/A
52	-1.27***	0.36	0.66	848
53	-0.83***	0.24	0.82	30,154
54	-0.93***	0.19	0.83	14,989
55	-1.04***	0.2	0.8	34,917

Thus we derive the effect of advalorem transport costs on exports. We are then able to infer that a 10% surcharge on the free on board price of iron ore and holding the latter price constant decreases the value of exports by 54.1% (table 5). While this measure may appear pronounced, the propagated impact of transport costs determinants on exports is dampened through table 3. Thus a 10% increase in distance traded increases the advalorem cost of shipping iron ore by 3.4%, and the Cost Insurance Freight (CIF) price at the destination becomes 103.4% of the initial free on board price of iron ore. Assuming that this adjustment does not alter the free on board price, the value of exports at the destination is reduced by 18.3%. Since factory prices of goods remain constant, this implies that the reduction in the value of exports comes in the form of reduced quantity traded from origin to destination by an amount of 18.3%. For the derivatives of iron ore commodities, the average corresponding impact on the value of exports is 10%, following a 10% change in distance.

Table 5: Elasticity of exports with respect to advalorem trade costs

NST/R	Commodity	Elasticity
41	Iron ore	5.41
45	Non-ferrous ores and waste	3.93
52	Semi-finished rolled steel products	3.54
53	Bars, sections, wire rod, railway and tramway track construction material	2.59
54	Steel sheets, plates, hoop and strip	2.31
55	Tubes, pipes, iron and steel castings and forgings	3.01

While the above estimates control for the variation across time, the following graphs present a snapshot of the empirical relations across time. For ore, the estimations are repeated using exporter, importer and commodity fixed effects within each year. The estimates of the elasticity of transport costs with respect to distance, the elasticity of exports with respect to distance, and finally the elasticity of exports with respect to transport costs are illustrated across time in each respective panel.

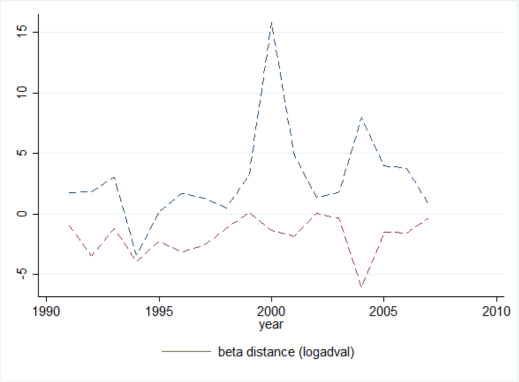

Figure 1: Elasticity of Ore transport costs with respect to distance.

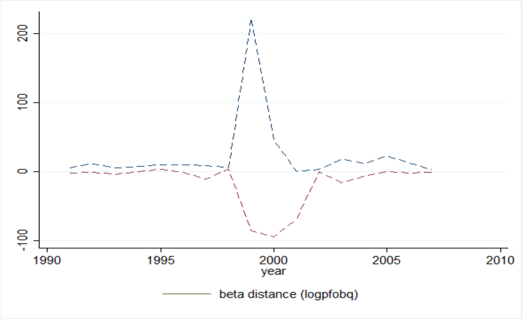

Figure 2: The elasticity of Ore exports with respect to distance.

3.1 MATERIAL FLOW SCENARIO RESULTS

As the projection for ore and steel demand are the product of a scenario exercise they reflect the individual progress in terms of steel intensity, ore production and export as well as the penetration of different steel production technologies. The steel demand associated with 2 indicative scenarios SSP 1 and SSP 2. SSP 2 arguably reflects a more conventional projection than SSP 1. Future Chinese steel production peaks by 2040 with projections comparable to those from Rio Tinto (2012) amongst others. Indian steel is still projected to grow significantly but not to same extent and mirrors projections in IEA (2012). However this is dependent on assuming steel intensity of GDP decreases after a period of stability. If current intensity (per GDP) is maintained the current production levels in India are set to double (comparable with some projections from Indian steel industry). Countries such as Turkey and Vietnam are projected to experience increases in steel production following a consistent increase in the steel intensity of GDP in recent years. In general terms most countries are projected to reflect a decrease in the ore intensity of GDP, taken to encompass not just technological advancement but also wider dematerialisation and efforts towards material efficiency. However for most countries, the reduction in the steel intensity of GDP is insufficient in the face of growing GDP to result in an absolute reduction in steel demand. Table 6 summarises the scenario projections based on both SSPs.

Table 6: Projections of Steel production.

		Steel Production Mt (SSP 2)			Steel Production Mt (SSP 1)		
	2010	2030	2040	2050	2030	2040	2050
China	638,743	1,148,658	1,314,511	1,019,350	998,534	997,522	728,168
Japan	109,599	100,490	95,364	89,871	101,978	97,912	93,552
United States	80,495	106,313	131,700	136,409	94,578	95,591	97,189
India	68,976	129,192	178,279	257,704	135,423	191,864	212,738
Russia	66,942	88,024	83,012	88,398	58,469	66,953	68,748
South Korea	58,914	114,417	136,970	153,983	40,768	35,163	27,953
Germany	43,830	59,331	79,662	87,833	28,789	17,278	19,723
Turkey	29,143	96,608	100,213	115,172	55,574	61,240	62,164
Brazil	32,948	49,865	41,565	49,768	52,770	49,333	57,566
Ukraine	33,432	55,991	67,871	79,044	44,750	59,922	78,106
Italy	25,750	20,872	18,666	16,306	20,711	18,020	15,637
Taiwan	19,755	32,575	35,495	36,544	32,638	35,454	35,786
Mexico	16,870	26,682	34,743	44,169	27,217	37,932	49,936
France	15,414	22,137	27,441	41,056	17,951	17,423	16,769
Iran	11,995	24,116	34,921	45,962	20,597	28,472	36,091
Others	179,959	259,616	317,594	382,037	247,806	309,678	380,104
Total	**1,432,765**	**2,334,887**	**2,698,007**	**2,643,606**	**1,983,120**	**2,125,708**	**1,987,350**

The total quantity of steel projected under SSP 2 is similar to the values projected in Allwood and Cullen (2009) and Bellevrat and Menanteau (2009). SSP 1 reflects a more challenging projection of the future as it envisions both significant economic growth as well as dematerialisation measures. In projecting steel demand within a SSP scenario retarding the growth in steel demand requires a significant reduction in ore intensity, with countries such as China projected to achieve an ore intensity comparable to current values for developed countries where the steel sector has matured (such as Canada and France). By 2050, this entails a 30% reduction in the steel intensity of GDP for many countries in comparison with the projections under SSP 2.

The physical quantity of ore required to sustain the steel demand summarised in the above tables is dependent not just on the absolute steel demand, but also the technology used to produce the steel and the quantity of domestic ore available in key steel producing countries. Whilst China has one of the largest ore reserves (USG 2014), the current and projected levels of production (Worldsteel, 2014) are insufficient to satisfy domestic demand and reserves are projected to be depleted within 30 years. For the purposes of this study, Chinese ore production is assumed to peak prior to 2020 and decline at the same rate as it grew since 2000, resulting in a depletion time comparable to Yellishetty et al. (2010) (albeit from a different start date). This means that Chinese ore is all but exhausted by 2050, ensuring the production of Chinese steel is dependent on imported ore. Given the significant growth in Australian and Brazilian ore production, assuming the same (exponential) growth rates results in significant increases in production, in excess of the projected growth in demand for global steel. For both countries, this increase affords a reduction in the proportion of domestic ore that is exported, sufficient to allow both counties to retain ore stocks and continue exporting in 2050. In conjunction with production estimates, the penetration of electric steel is projected based on the SSP scenario framing. Under SSP 2 by 2050 approximately 38% of global steel is projected to be produced using this method. Reflecting the narrative of dematerialisation, under SSP 1, the penetration of this technology is assumed (by 2050) to reach 50% and 80%, the later within a 2 °C scenario. Both these are chosen to approximate the tonnage of electric steel expressed by Bellevrat and Menanteau (2009) under conventional (taken as a 4 °C scenario) or 2 °C scenarios, which also projects similar increases in steel demand by 2050. In terms of ore, the imports and exports associated with these three scenarios are summarised in tables 7-9 below. The regional groupings are taken from MSI (2014). Under SSP 2 the growth in ore trade occurs broadly in line with steel trends until 2040 but decreases thereafter based on increasing uptake of electric arc furnace and stagnating steel demand. However a crucial determinant is the extent to which Chinese steel mills incorporate this technology.

Table 7: Ore imports by export and import region based on SSP 2 and 4 °C.

Seaborne Ore Imports by Region (Mt)				Seaborne Ore Exports by Region (Mt)			
	2010	2030	2050		2010	2030	2050
Canada	8	2	3	Canada	33	30	30
United States	6	7	28	United States	10	5	11
Latin America	12	15	42	Latin America	341	721	792
Western Europe	119	140	157	Scandinavia	23	10	11
Eastern Europe + FSU	36	9	19	Eastern Europe + FSU	73	47	65
Africa	7	11	16	South Africa	48	9	2
Middle East	21	16	20	Other Africa	11	37	35
China	619	1,869	1,890	Middle East	21	34	5
Japan	134	102	89	India	96	123	172
South Korea	56	61	73	Oceania	404	1,227	1,212
Taiwan	19	27	28	Other	19	26	44
Other	7	10	6				
Total	**1,043**	**2,269**	**2,372**	**Total**	**1,080**	**2,269**	**2,378**

Data since 1980 suggest that as GDP increases, the proportion of steel produced electrically declines (Worldsteel, 1980-2014). For China the correlation between per capita GDP and % electric steel is maintained, meaning that by 2050 China demonstrates one of the lowest penetration rates for electric steel. However as SSP 1 presents a narrative of increased material efficiency it is assumed that there is a significant increase in the availability of recycled steel. In developing a scenario based on SSP 1, increased uptake of electric steel is assumed, representing 50% and 80% of global production by 2050, with the later seeking to reflect decarbonisation towards a 2°C budget.

Table 8: Ore imports by export and import region based on SSP 1 and 4 °C.

Seaborne Imports by Region (Mt)				Seaborne Exports by Region (Mt)			
	2010	2030	2050		2010	2030	2050
Canada	8	3	4	Canada	33	30	30
United States	6	25	5	United States	10	5	8
Latin America	12	15	46	Latin America	341	470	377
Western Europe	119	93	106	Scandinavia	23	10	11
Eastern Europe + FSU	36	9	18	Eastern Europe + FSU	73	47	65
Africa	7	10	26	South Africa	48	9	2
Middle East	21	15	17	Other Africa	11	37	35
China	619	1,381	953	Middle East	21	34	2
Japan	134	87	89	India	96	123	112
South Korea	56	21	13	Oceania	404	903	621
Taiwan	19	23	27	Other	19	26	44
Other	7	11	3				
Total	**1,043**	**1,693**	**1,307**	**Total**	**1,080**	**1,694**	**1,307**

The 2 °C scenario seeks to manifest the broader sustainability narrative of SSP 1 through choices of both steel intensity and technology mix. As can be seen in tables 8 and 9 increasing the use of electric arc furnaces has a significant impact on traded ore, particularly in relation to Chinese ore demands, resulting in a significant decrease in traded quantity, particularly by 2040. The viability of such projection would be contingent on the availability of scrap as a source of iron but also on the decarbonisation of the electric grid and an emission cap.

Table 9: Ore imports by export and import region based on SSP 1 under a 2 °C budget.

Seaborne Imports by Region (Mt) 4°C				Seaborne Exports by Region (Mt) 2 °C			
	2010	2030	2050		2010	2030	2050
Canada	8	3	4	Canada	33	30	30
United States	6	13	0	United States	10	5	3
Latin America	12	15	17	Latin America	341	383	66
Western Europe	119	93	88	Scandinavia	23	10	7
Eastern Europe + FSU	36	9	14	Eastern Europe + FSU	73	53	68
Africa	7	10	19	South Africa	48	9	2
Middle East	21	15	9	Other Africa	11	37	15
China	619	1,068	225	Middle East	21	34	1
Japan	134	87	31	India	96	58	23
South Korea	56	21	10	Oceania	404	723	186
Taiwan	19	23	9	Other	19	26	28
Other	7	11	3				
Total	**1,043**	**1,368**	**429**	**Total**	**1,080**	**1,368**	**430**

4. DISCUSSION

In seeking to ascertain the elasticity of iron and steel related goods the lack of sufficient observations for NST/R groups 41, 45, 46 and 52 does not permit inference regarding the stability of the estimates across the 1991-2007 time period. For NST/R group 53, the elasticity of exports with respect to advalorem costs are decreasing in absolute value across time to below 2. The same pattern holds for “54 Steel sheets, plates, hoop and strip” which reaches the elasticity of around 2, however the sensitivity is increased in absolute value in the last year of the sample. Lastly, the elasticity for “55 Tubes, pipes, iron and steel castings and forgings” is undulating around the mean of 3 across the time period. Since no understanding about the iron ore group is deduced, the combined elasticities of all other groups which across time have an average of roughly 3, coupled with the fact that the sample estimate in table 5 is revealed to be 5.41, allows us to make the statement that the true elasticity of exports of iron ore with respect to advalorem costs lies somewhere between these two bands.

The results presented in section 3.1 reaffirm the importance of distance as a determinant in the pattern of trade for iron ore. This in itself is a valuable insight as it can inform scenarios exercises such as presented here. In this instance the importance of distance has influenced the choice of export rates (as a proportion of production) for key regions such as Brazil and Australia. Specifically given its geographic proximity to the largest ore importer (in this case China), it is assumed within these scenarios that Australia remains the most significant ore exporter. In that regard econometric analysis can support scenario work in this instance by providing guidance on the factors which might influence choice of trading partners. Such analysis can also provide some contextualisation on what changes to the wider system would likely be required in order to facilitate dramatic changes to the existing system, such as the necessary changes in transport cost associated with increasing distances between import and export centres. However it should be mentioned that the scenario method presented here, reflects a simplification of a complex system, with assumptions that (for example) the proportion between seaborne and overall trade does not change significantly. At this point it should be reiterated that scenario analysis is employed as a hypothetical tool to explore how changing assumptions on elements such as technology or domestic production may impact upon trade. For example, India was (until recently) a significant exporter of Iron ore but with the introduction of export duties (partially as a reduced cost of ore following expanded production in Australia and Brazil) exports dropped dramatically from 2011. An assumption within the scenarios presented here is that Indian ore exports resume and subsequently grow. (This is based on the broader narrative for both SSP whereby key developing regions experience significant economic growth and the Indian mining industry is invested in on the assumption that steel demand will increase.) Adopting country specific criteria can identify individual factors (such as electric steel in China) which can have a significant impact on overall demand. The results presented here demonstrate the large-scale changes in the wider system necessary to precipitate a drastic reduction in trade, such as policies of aggressive material recovery in the industrial and automotive sector. Whilst econometric analysis provides a statistical robustness that cannot be replicated in a bespoke method, it has lesser capacity for it to encompass specific physical constraints. For example, based on published reserves (UGS, 2014) it is likely that South African ore will be depleted prior to 2050, which will have an impact on its trading partners. By way of example, the 2050 ore trade estimate for SSP 2 is recalculated with the modification that both Australia and Brazil have exceeded their ore reserves and no longer produce or export ore, whilst overall demand for steel remains the same. Under such a scenario it may be envisioned that regions such as Russia, West Africa and India (with comparatively large and high quality ore reserves) may represent viable alternative sources of ore. Under such an example these three regions (Eastern Europe, West Africa and India) are projected to contribute to 85% of global exports. This simple example is presented to illustrate how the distribution of trade is currently dependent on a relatively constrained group of exporters. Whilst the results above reflect decisions made within a scenario generation exercise, however given that these regions reflect large ore reserves, such a projection is not considered implausible.

5. CONCLUSIONS

An econometric assessment of the drivers of trade have reiterated the importance of distance in helping determine the distribution of trading partners. Results suggest that a 10% surcharge on the free on board price of iron ore decreases the value of exports by 54.1%. A 10% increase in distance traded increases the advalorem cost of shipping iron ore by 3.4%, and the CIF price at the destination becomes 103.4% of the initial fob price of iron ore. Assuming that this adjustment does not alter the fob price, the value of exports at the destination is reduced by 18.3%. Based on established trends in economic growth and steel production the future steel intensity of GDP is projected as part of a scenario process which seeks to take decarbonisation into account. In maintaining current trends under a scenario with moderate economic growth, steel production and traded ore may double by 2050. If however a 2°C emission budget is satisfied within the context of aggressive dematerialisation and technology uptake, a drastic reduction in the quantity of traded ore is projected but can only be achieved by changes to the wider energy system and domestic steel recovery. Material flow analysis demonstrates that current patterns of iron ore trade are heavily influenced by a small number of countries and reinforces how future trade will reflect for example when domestic Chinese, Australian and Brazilian ore production will peak, as well as the level of technology uptake for electric steel production.

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