Policy Paper

Downstream Beneficiation:

A cross-country analysis of factors underlying the emergence of a steel industry[1]

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Abstract

This paper empirically investigates the major factors that have supported the development of steel industries across countries. While technological capacity has become an important enabling factor for steel production in recent years, the demand for steel and the availability of energy (electricity, metallurgical coke, and natural gas) have remained key elements over time. In emerging and developing economies, the availability of raw materials, namely the production of iron ore, was also identified as an additional determining factor for steel production. In advanced economies, imports of steel scrap have facilitated steel production. The results are robust to alternative specifications, additional control variables, and the use of various processes for steel production.

Keywords: steel production, steel export, enabling factors

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I. Introduction

In the quest for better economic prospects, many resource-rich countries seek to move away from exporting raw materials and into developing domestic transformation capabilities, in the hopes of creating jobs, enhancing skills through the transfer of technological and managerial knowledge, and, ultimately, diversifying the economy. Countries with a diversity of resources, such as Australia, South Africa, Oman, and Ukraine, have successfully developed steel industries from varying circumstances and conditions. For instance, Australia developed its steel industry tapping into vast iron ore and coal reserves, along with a sizeable domestic demand for steel. Lacking significant iron ore deposits, Oman relied primarily on a stable supply of natural gas to grow a steel industry. In Ukraine, direct foreign investment helped acquire advanced technologies and skills to support the steel industry (Talkin, 2016a; Talkin, 2016c.). Additionally, for many of these countries, domestic endowments and initial comparative advantages did not prevent a loss of competitiveness in the steel sector overtime.

Countries have not hesitated, in many cases, in providing large incentives to investors and firms for downstream industry developments like steel plants. Yet, the literature provides little evidence on the prerequisites to successfully develop a steel industry.

In his 1928 paper, the geographer Richard Hartshorne attempted to provide initial evidence on the factors determining the location of the iron and steel industry (Hartshorne, 1928). Challenging the generally accepted explanation "Iron moves to coal," Hartshorne (1928) advances three major factors affecting the location of a steel industry: *(i)* the proximity to iron ore production, *(ii)* the proximity of coal production (especially coking coal), and *(iii)* the proximity of markets for steel consumption. While recognizing the equal importance of these three factors, Hartshorne (1928) highlights the "market factor," the first factor, as somewhat more important than the other two. Indeed, he stresses that iron moves toward coal fields, but to a greater extent iron transitions because the largest markets for steel products tend to be developed in proximity of coal fields.

The locational factors in the iron and steel industry appear to have evolved over time. In the mid-twentieth century, Isard (1948) highlighted important changes in the location of steel plants as the role of coal declined considerably. The use of higher pressures in the blast furnace, the presence of oxygen and enriched air in steel furnaces, and less energy intensive scrap contributed to the decline of iron ore and coal consumption. According to Isard (1948), these coke-saving technologies have reduced the transportation-cost of coal, and, as a result, the associated locational pull of coal became less important and market pull factors became more important.

Hekman (1978) advanced a pioneering econometric analysis explaining the location of iron and steel production. The author showed that three U.S. production centres (Pennsylvania, Ohio, and Illinois-Indiana) became major steel producers by combining low input costs with a good distribution network to steel markets. That said, in contrast to Isard (1948) and Isard and Capron (1949), Hekman shows that regional cost differentials play only a minor role in explaining the differential growth among production centres, while instead higher demand from steel-using industries has been the key factor. Karlson's (1983) cross-sectional analysis, however, opposes Hekman's results by showing that the optimal location of steel production is determined by transportation cost minimization, in line with Isard's (1948) and Isard and Capron's (1949) conclusions. Furthermore, Markusen (1986) points out that instead of steel producers moving towards steel-using industries, the latter may be moving towards the former. For example, the development of a steel industry in Chicago attracted large steel-using industries to the region. Steel producers also moved towards steel-using industries such as shipbuilders and car manufacturers in South Korea.

Most of the literature has focused on the U.S. and lacks conclusive evidence concerning the factors that determine the locations of steel production. In more recent years, the emergence of key players, such as China, may have also affected any previously established evidence. This paper contributes to the literature by providing a systematic cross-country analysis of key factors that explain steel production. In particular, it investigates the potential changes in the determinants overtime and any heterogeneity that may exist between advanced and emerging market economies. The paper also assesses the robustness of the results to alternative specifications, additional control variables, and the use of various processes for steel production.

The remainder of the paper is organized as follows. Section 2 provides some stylized facts on iron ore and steel, including key trends and changes overtime. Section 3 describes the empirical model and discusses the results. The last section provides concluding remarks.

II. Iron Ore and Steel: Some Stylized Facts

Most of the world's crude steel is produced by emerging and developing countries, according to data from the World Steel Association.[2] While steel production by advanced economies have remained broadly stable since the 1990s, the emergence of China as a global economic powerhouse has markedly changed the trend of steel production in emerging and developing countries. Steel production in emerging and developing economies more than doubled between 2000 and 2014, primarily in China (Figures 1a). The country's strong growth, including the construction sector, during recent decades has been accompanied by a strong, domestic demand for steel. The 2007-2009 Great Recession brought an end to the steady increase (since the early 1990s) in steel production for advanced economies. However, the crisis only had a short-lived impact on the steel production of emerging and developing economies (Figure 1a).

Concomitantly with the steady increase in steel production, the production of iron ore has also sharply increased, notably since the early 2000s. Iron ore is mined in nearly 50 countries, but the majority of iron ore comes from a small number of countries: Australia, Brazil, China, India, Russia, and the U.S. Of these countries, Australia and Brazil dominate the world's iron ore export, each country having about one-third of total iron ore export (see WSA, 2018).

Steel is often produced through two processes. *(i)* blast furnace (BF) and basic oxygen furnace (BOF) and *(ii)* electric arc furnace (EAF). In both advanced and developing countries, BOF is the most used process for steel production. Around 70 percent of worldwide steel is produced through the BOF route (see WSA, 2018). Overtime, in particular in advanced countries, the EAF route has become more widely used (Figure 1b). While, both technologies use steel scrap for steel production, the electric arc furnace technology relies more heavily on scrap compared to the BOF route.

While emerging market economies and developing countries produce most of the steel and iron ore, advanced countries are the main exporters of steel. Since the beginning of the 2000s,

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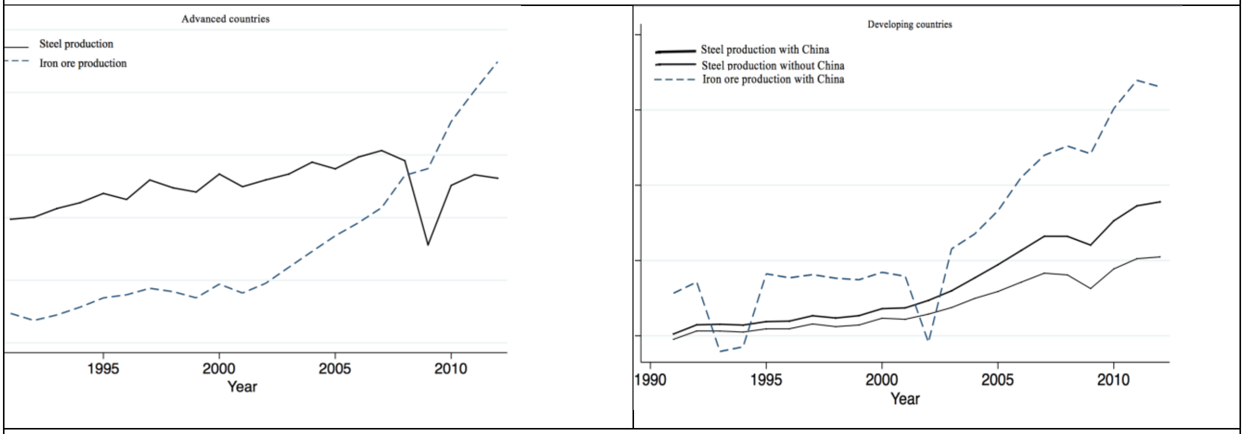
[2] Steel production, steel export, steel use, and iron ore production data are from the World Steel Statistical Yearbook provided by the World Steel Association (WSA). Metallurgical coke and natural gas production data as well as electricity data are from the International Energy Statistics provided by the US Energy Information Administration (EIA). R&D investment data is from the Analytical Business Enterprise R&D database.

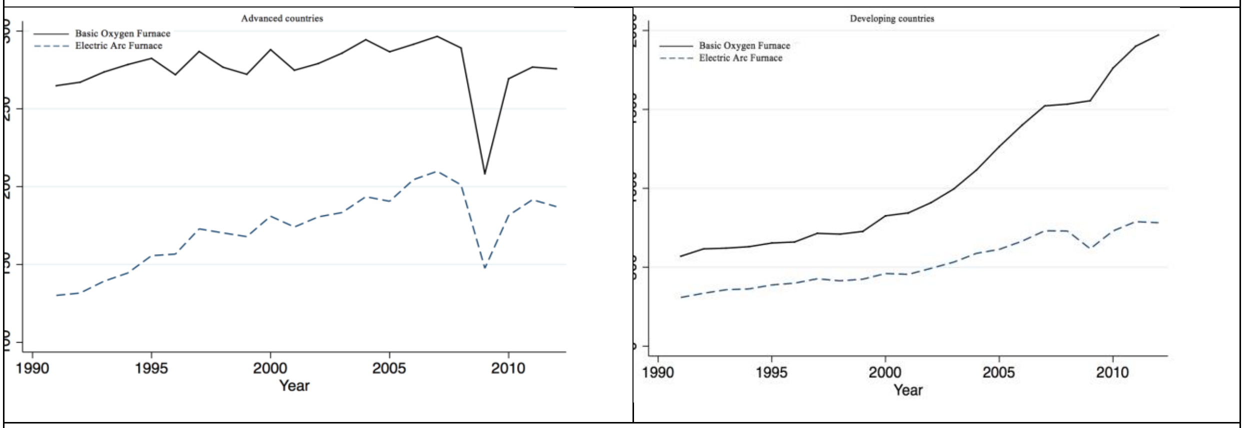
steel export by developing countries has increased sharply, mainly in China, closing the gap with advanced economies (Figure 1c).

Figure 1. Trends in Iron Ore and Steel Production and Steel Export

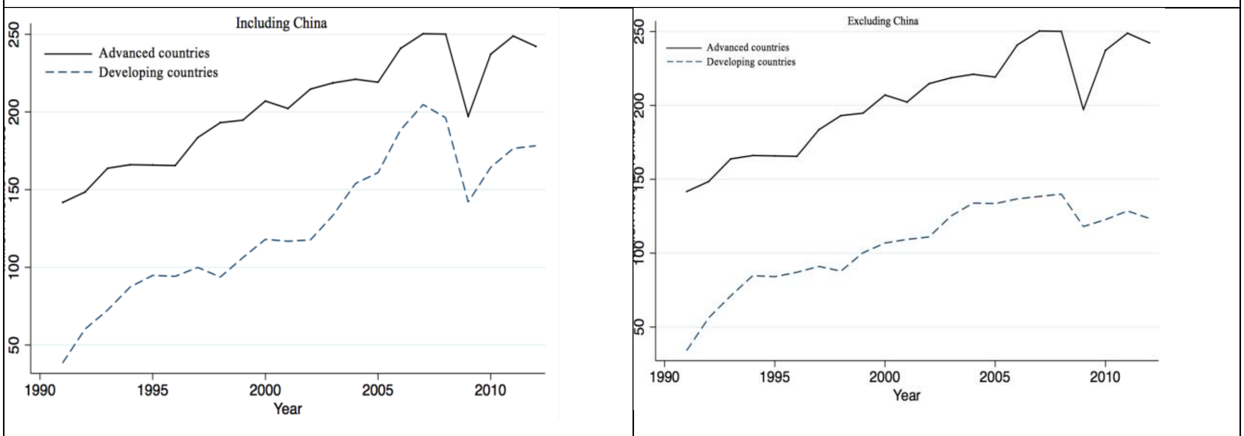
1.a. Steel and Iron Ore Production: Advanced and Developing Economies



1.b. Steel Production by Process: Advanced and Developing Economies



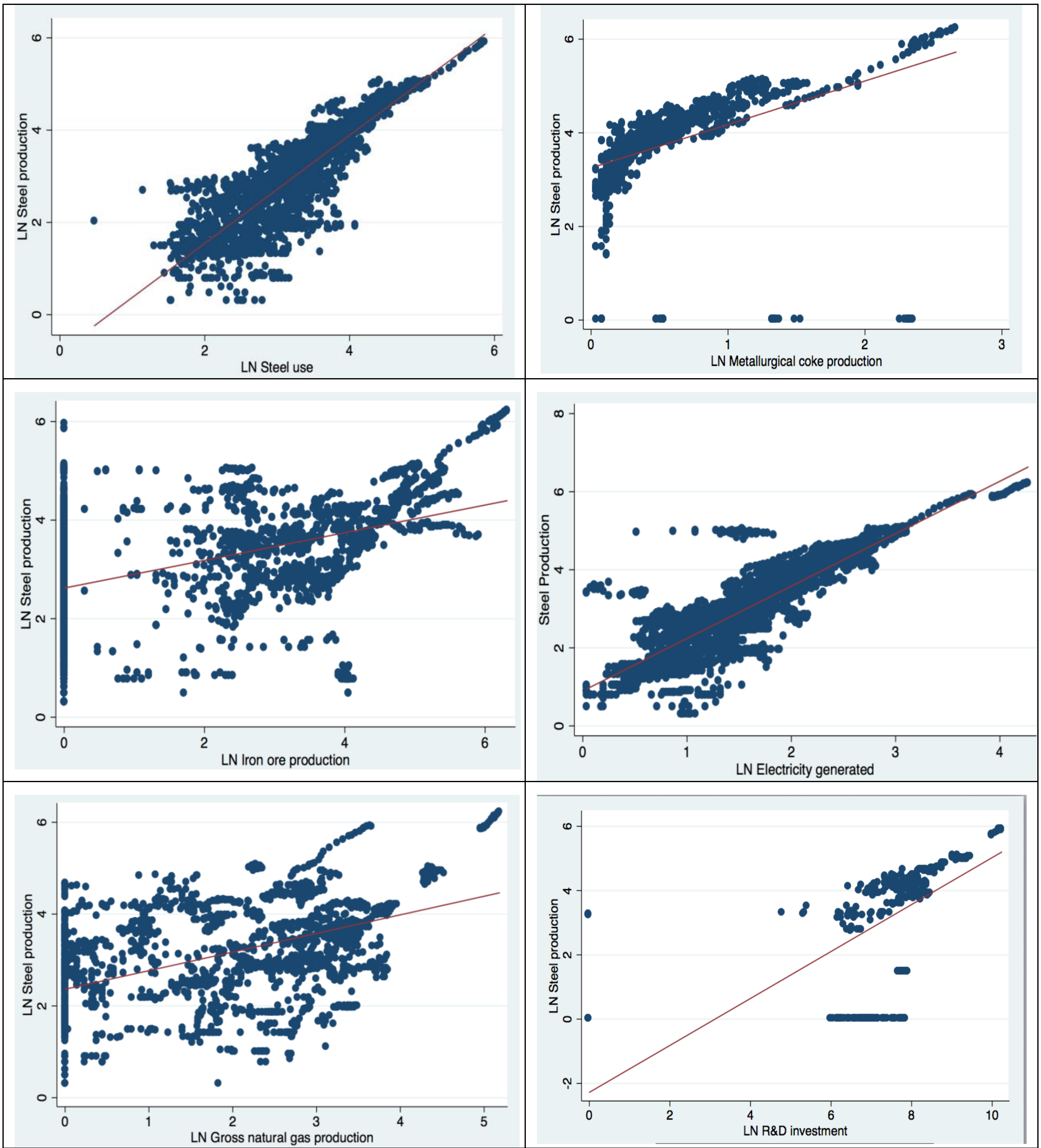
1.c. Steel Export: Advanced and Developing Economies (with and without China)



Authors' estimates.

A further look at the data suggests a strong correlation across countries between steel production and steel use (Figure 2**)**. The production of iron ore and various forms of energy inputs, including electricity, metallurgical coke, and to some extent natural gas, are also positively correlated with the level of crude steel production. The correlation is particularly strong between electricity generation and crude steel production. Technological progress, captured by R&D investment, also appears positively correlated with steel production.

Figure 2. Correlation between Crude Steel Production and some Explanatory Variables



Source: Authors' estimates.

III. Empirical Framework

This section goes beyond simple correlations to formally assess the potential determinants of crude steel production. The empirical analysis relies on a cross-country panel data covering 32 advanced economies and 70 emerging and developing economies over the period 1980 to 2014.[3]

The empirical model builds upon the existing literature to include three major factors identified as critical determinants in the emergence of steel production: *(i)* availability of iron ore, the raw material; *(ii)* availability of energy, a key input; and *(iii)* demand for steel, the final product (Hartshorne, 1928; Isard, 1948; Hekman, 1978).

Equation 1 describes our baseline empirical model. It explains the production of crude steel: the dependent variable (*Steel production*) by the total production of iron ore (*Iron*), the demand for steel captured by each country use of steel (*Steel use*), and a set of variables capturing the availability of energy (*Energy*) such as the production of *metallurgical coke*.[4] The production of steel is energy intensive. According to estimates from the World Steel Association, energy constitutes 20% to 40% of the steel production costs in some countries, and about 50% of an integrated facility's energy input comes from coal, 35% from electricity, 5% from natural gas and 5% from other gases (see WSA, 2016). Hence, we include in our empirical model variables to capture *electricity generation* and the production of metallurgical coke and *natural gas*. Formally, our empirical model is:

$$SteelProd_{it} = \alpha Iron_{i,t} + \beta SteelUse_{i,t} + \gamma Energy_{it} + \varphi Control_{it} + \nu_i + \eta_t + \varepsilon_{it} \quad (1)$$

where *i* and *t* represent countries and years, respectively. ν_i represents country-fixed effects, η_t time-fixed effects, and ε_{it} is the error term. The model also includes a number of control variables (*Control*) such as *R&D investment* in the iron and steel sector, imports of *steel scrap*, and maritime *transport cost*. R&D investment is included to capture technological advancement as the steel industry has become more technology-intensive overtime. Import of steel scrap controls for the rise of scrap as a major input for steel production, especially through the EAF route. Maritime transport cost is included to control for the decline in

[3] Appendix 1 provides the list of countries included in the analysis.

[4] Metallurgical coke is an essential fuel in the steelmaking process and it is created by heating metallurgical coal.

transport costs, which could make it more attractive for some countries to export iron ore instead of processing it domestically. As stationarity tests strongly reject the null of a unit root for the variables, we rely on fixed-effects estimations as our baseline method (Table A1).[5]

IV. Results

A. Steel production

Table 1 presents the results of various estimations. Looking at the entire sample of advanced, emerging, and developing economies over the full period (column 1), the production of iron ore, the use of steel, and the availability of energies such as electricity and metallurgical coke are positively and significantly associated with steel production. Additionally, GDP per capita is negatively associated with steel production. This may reflect the fact that among emerging market economies, countries with the largest per capita income (for instance oil rich countries such as Kuwait, Qatar, and the United Arab Emirates) do not have sizeable steel production.

Column 2 and 3, respectively analyse advanced economies and emerging and developing economies during the period 1980-2014. In advanced economies (column 2) demand for steel and the availability of energy (electricity and metallurgical coke) are all associated with higher steel production. Unlike in emerging and developing economies (column 3), the availability of the raw material, iron ore, does not appear as important of a factor for steel production in advanced economies. This finding corroborates the fact that steel production in some advanced countries relies mainly on iron ore imports from countries, such as Brazil and Australia.

[5] Appendix 2 provides a definition of each variable and Table A2 presents descriptive statistics.

Table 1: Determinants of Steel Production: Advanced vs Developing
Fixed effects regressions (Unbalanced Panel)

	All countries (1)	Advanced countries (2)	Developing countries (3)	1980-2002 (4)	2003-2014 (5)
LN Steel use	0.305***	0.229***	0.166***	0.379***	0.254***
	(0.0316)	(0.0300)	(0.0531)	(0.0353)	(0.0821)
LN Iron ore Production	0.0311***	0.00214	0.0655***	0.0192***	0.117***
	(0.00555)	(0.00322)	(0.0120)	(0.00630)	(0.0147)
LN Electricity Generated	0.403***	0.0601**	0.769***	0.320***	0.123
	(0.0394)	(0.0258)	(0.0843)	(0.0467)	(0.103)
LN metal. coke Production	0.570***	0.575***	0.469***	0.587***	0.704***
	(0.0476)	(0.0422)	(0.0737)	(0.0577)	(0.110)
LN GDP per Capita	-0.165***	0.334***	-0.168*	-0.241***	0.0222
	(0.0615)	(0.0663)	(0.0909)	(0.0790)	(0.194)
Constant	2.153***	1.179***	1.700***	2.437***	1.839***
	(0.219)	(0.249)	(0.313)	(0.258)	(0.694)
Observations	1,138	550	588	724	414
R-squared	0.723	0.843	0.746	0.689	0.391
Number of countries	42	20	22	38	38

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Column 4 and 5 identify the time period before the surge in steel production and steel export by emerging economies (i.e. before 2003) and the time period after this surge (i.e. after 2003).[6] In the period before 2003 (column 4), iron ore production, steel use, and the availability of energies (electricity and metallurgical coke) are all positively and significantly associated with steel production, while GDP per capita has a negative effect on steel production. Focusing on the latter period (2003-2014), when China along with few emerging market economies arose as dominant global steel producers, the amount of electricity generated no longer had a significant effect. As can be seen from Figure 1b, in developing countries steel is mainly produced through the blast furnace route while the electric arc furnace route is used less often when compared to advanced economies. This may explain why electricity, which is an essential energy input for the electric arc furnace route, no longer has a significant effect.

Table 2: Determinants of Steel Production: additional control variables (1991-2014)

[6] The limited number of observations does not allow for a meaningful simultaneous breakdown by type of economies (advanced versus emerging and developing) and by time period (before and after 2003).

Fixed effects regressions (Unbalanced Panel)

	All countries (1)	Advanced countries (2)	Developing countries (3)	All countries (4)
LN steel use	0.208***	0.193***	-0.0279	0.149***
	(0.0292)	(0.0411)	(0.0486)	(0.0539)
LN iron ore production	0.00898*	-0.00114	0.0212*	-0.0109
	(0.00498)	(0.00441)	(0.0110)	(0.0120)
LN electricity generated	0.388***	0.0941**	0.891***	0.254***
	(0.0364)	(0.0383)	(0.0645)	(0.0862)
LN metal. coke production	0.673***	0.678***	0.503***	0.657***
	(0.0489)	(0.0603)	(0.0704)	(0.127)
LN GDP per capita	-0.0958	0.0185	0.0186	
	(0.0698)	(0.107)	(0.0915)	
LN Steel scrap imports	0.00422	0.0370***	-0.00436	-0.00536
	(0.00612)	(0.00892)	(0.00778)	(0.0132)
LN nat. gas production				0.0109
				(0.0161)
LN R&D investment				0.00826**
				(0.00334)
LN transport cost				-0.0196
				(0.155)
Constant	2.345***	2.560***	1.652***	2.503***
	(0.252)	(0.444)	(0.312)	(0.275)
Observations	616	341	275	100
R-squared	0.796	0.682	0.890	0.701
Number of countries	32	16	16	9

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2 supplements the baseline regressions with additional control variables. Because of missing values, the regressions including the additional variables cover only the period of 1991-2014. Greater import of steel scrap is associated with higher steel production in advanced countries (column 2) but not in emerging and developing countries (column 3). Column 4 includes additional control variables: natural gas production, R&D investment in the iron and steel industry, and maritime transport cost of exporting iron and steel.[7] The results in column 4 highlight that while iron ore is no longer significantly associated with steel production, R&D investments are associated with higher steel production, suggesting the steel industry has become more technology intensive overtime. Higher maritime transport

[7] The regression excludes the GDP per capita variable, which is correlated with R&D investments, to reduce multicollinearity (Braconier, 2000).

cost is negatively associated with steel production, although the coefficient is not significant. This result could reflect the significant reduction of transport costs which occurred in the years prior to the time-period covered in the analysis (see Lundgren, 1996). As such, the marginal differences in transport costs between 1991 and 2014 do not significantly explain differences in steel production. The production of natural gas also does not seem to be associated with higher steel production.

B. Steel production by production process

As mentioned before, there are two main processes for steel production (blast furnace [BF] and basic oxygen furnace [BOF]; or electric arc furnace [EAF]). Table 3 analyses the enabling factors for each type of steel production.[8] Column 1 displays the results of the estimation for steel production through the BOF. The results show that the production of iron ore, metallurgical coke, and electricity are associated with higher steel production through basic oxygen furnace technology, while the size of domestic demand is insignificant.

Column 2 examines steel production through electric arc furnace. EAF is mostly used in advanced economies, as confirmed by the positive and significant association between per capita income and steel production. Results from column 2 highlight that the production of iron ore and metallurgical coke are not associated with higher steel production through EAF. These findings corroborate the fact that EAF is a more efficient process in the sense that it requires on average less iron ore and metallurgical coke to produce the same amount of steel compared to the BOF process. As expected, electricity production is associated with higher steel production through EAF. While the size of domestic demand provides little support for steel produced through BOF, it is associated with larger steel production through EAF. An intuition of this contrast could be that advanced economies, which do not necessarily produce iron ore, can import raw material to produce steel using the more efficient EAF process, so long as there exists a domestic demand of steel to satisfy.

[8] The limited number of observations does not allow for a meaningful simultaneous breakdown by time period (before and after 2000).

Table 3: Determinants of steel production by production route

Fixed effects regressions (Unbalanced Panel)

	BOF (1)	EAF (2)	BOF (3)	EAF (4)
LN Steel use	-0.00899	0.619***	-0.0502	0.517***
	(0.0328)	(0.0715)	(0.0373)	(0.0655)
LN Iron ore Production	0.0149**	0.0189	0.0115*	0.0286**
	(0.00600)	(0.0130)	(0.00635)	(0.0111)
LN Electricity Generated	0.166***	0.189*	0.146***	0.159*
	(0.0447)	(0.0974)	(0.0465)	(0.0816)
LN metal. coke Production	1.130***	-0.128	1.349***	-0.0223
	(0.0504)	(0.110)	(0.0624)	(0.109)
LN GDP per Capita	0.0996	0.533***	0.0419	0.316**
	(0.0735)	(0.161)	(0.0891)	(0.156)
LN Steel scrap imports			-0.0253***	0.0392***
			(0.00780)	(0.0137)
Constant	2.303***	-1.756***	2.750***	-0.442
	(0.265)	(0.579)	(0.322)	(0.564)
Observations	813	805	616	615
R-squared	0.660	0.443	0.749	0.533
Number of countries	38	39	32	32

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Steel scrap imports are associated with higher steel production through the EAF route, but with lower steel production through the BOF route (columns 3 and 4). This finding may reflect the fact that major importers of steel scrap such as Turkey and several advanced countries mostly use the EAF technology for steel production.

C. Steel export

The decline in maritime transport cost to export iron and steel as well as efficiency gains in the production of steel have led to a sizeable increase in steel export. While trade and other barriers combined with a sizable domestic market may help countries produce steel for domestic consumption, exporting steel requires international competitiveness. Factors supporting the production of steel may differ from those important for steel export. Table 4 analyses driving factors for steel export. The results show that while domestic demand matters little for steel export in advanced economies, high domestic demand is associated with lower export from developing countries. As for steel production, the availability of iron ore is associated with higher export only in developing countries. Energy inputs (electricity and metallurgical coke) are also associated with higher steel export, particularly in developing countries.

Table 4: Determinants of Steel Export
Fixed effects regressions (Unbalanced Panel)

	All countries (1)	Advanced countries (2)	Developing countries (3)	1980-2002 (4)	2003-2014 (5)
LN Steel use	-0.0239	-0.0613	-0.489***	-0.00100	-0.302**
	(0.0846)	(0.0987)	(0.142)	(0.111)	(0.129)
LN Iron ore production	0.0464***	-0.000702	0.0733**	0.0807***	0.0103
	(0.0147)	(0.0106)	(0.0312)	(0.0195)	(0.0241)
LN Electricity Generated	0.649***	-0.135	1.590***	0.735***	0.290*
	(0.108)	(0.0848)	(0.232)	(0.152)	(0.157)
LN metal. coke production	0.920***	0.277**	0.596***	1.123***	0.766***
	(0.126)	(0.139)	(0.189)	(0.179)	(0.171)
LN GDP per Capita	-0.256	0.869***	0.211	-1.003***	0.101
	(0.164)	(0.219)	(0.231)	(0.250)	(0.298)
Constant	2.704***	0.247	0.329	5.394***	3.255***
	(0.588)	(0.822)	(0.802)	(0.817)	(1.096)
Observations	1,072	540	532	673	399
R-squared	0.534	0.483	0.638	0.486	0.144
Number of countries	40	20	20	37	36

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Column 4 and 5 disaggregate the above results by analysing the period before the surge in steel production and export by emerging economies (i.e. before 2003) and the period after this surge. Column 4 investigates steel export during the period when advanced countries dominated the international steel market. The results show that energy availability, namely electricity and metallurgical coke, as well as iron ore production were associated with higher levels of steel export. These results are broadly similar to those in Table 1, column 4, which looks at the determinants of steel production during the same period.

Column 5 explores steel export during the surge in steel production export by emerging market economies (i.e. after 2003). Focusing on the period 2003-2014, the availability of iron ore, the raw material, arises not as an important factor for the export of steel in this period, yet available energies, namely electricity and metallurgical coke, are significantly correlated with steel production. This contrasts with the results in Table 1 column 5 which show that iron ore production is associated with higher levels of steel production during the same time period. This may reflect an improved ability to import iron ore and transform it into steel for many countries--thanks to the development of transportation infrastructure, lower transportation costs, and a supply of available and reliable energy. As a result, the international, competitive position of steel exporters that depend on iron ore imports may have improved relative to the competitive position of steel exporters that depend on domestic iron ore. Steel scrap imports are also associated with higher steel production in advanced economies (Table A3). The rise of China as a major steel producer and its ensuing excess capacity has made the export market for steel more competitive and could impact the results.

Concluding Remarks

This cross-country study identified the major factors affecting the emergence of steel industries in advanced and developing economies. It shows the demand for steel and energy inputs have remained important factors overtime in steel production for both advanced and developing economies. With the emergence of China as a major steel producer during recent decades, this paper points out the determinants of steel production have also changed over time. In particular, technological progress has become an important factor associated with steel production in advanced and emerging market economies. The findings are robust to alternative specifications, additional control variables, and the use of various processes for steel production, but they also highlight interesting heterogeneities, including across country groups. While the production of iron ore, the raw material, is important for steel production in emerging and developing economies, it is not a determining factor in advanced countries. Steel scrap imports are associated with higher steel production in advanced countries.

In a nutshell, two traditional factors, energy and demand, have remained important for steel production, and a new element, technology, has emerged in recent years. Developing and emerging economies with iron ore deposits and aiming to develop a steel industry would need to secure competitive energy supply, develop, or be able to absorb steel-related technologies. This could be fulfilled through a skilled labour force while also having a sizeable domestic market for steel consumption--or at least adequate infrastructure to supply international markets.

APPENDIX

Appendix 1: List of countries

Advanced economies: Australia, Austria, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Taiwan Province of China, United Kingdom, and United States of America.

Developing and emerging economies: Albania, Algeria, Angola, Argentina, Azerbaijan, Bahrain, Bangladesh, Belarus, Bosnia and Herzegovina, Brazil, Bulgaria, Chile, China, Colombia, Democratic Republic of the Congo, Croatia, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Georgia, Ghana, Guatemala, Honduras, Hungary, India, Indonesia, Iran, Iraq, Jordan, Kazakhstan, Kenya, Libya, Macedonia (FYR), Malaysia, Mauritania, Mexico, Moldova, Mongolia, Montenegro, Morocco, Myanmar, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Saudi Arabia, Serbia, South Africa, Sri Lanka, Syria, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Vietnam, and Zimbabwe.

Appendix 2: Description of Variables

Variable	Definition
Dependent	
Steel production	Total Production of crude steel, thousand tonnes
Steel export	Exports of semi-finished and finished steel products, thousand tonnes
BOF steel production	Production of crude steel in oxygen-blown converters, thousand tonnes
EAF steel production	Production of crude steel in electric furnaces, thousand tonnes
Independent	
Natural gas production	Gross natural gas production, billion cubic feet
Metal. coke production	Production of metallurgical coke, million metric tons of oil equivalent
Electricity generated	Total electricity net generation, billion kilowatt-hours
Steel use	Apparent steel use (finished steel products), thousand tonnes
Iron ore production	Production of iron ore, thousand tonnes
GDP per capita	Gross domestic product per capita, USD 2011
R&D investment	R&D investment iron and steel industry, USD 2010
Maritime transport cost	Average unit transport cost of iron and steel (exporting country)
Steel scrap imports	Imports of scrap, thousand tonnes

Table A1: Unit Root Tests

	Fisher-type unit-root test based on augmented Dickey-Fuller tests	
	Statistics	P-value
Steel production	135.3	0.0009
BOF steel production	240.8	0.0000
EAF steel production	177.3	0.0000
Steel export	316.8	0.0000
Steel use	195.3	0.0000
Metallurgical coke production	138.2	0.0003
Iron ore production	207.5	0.0000
Electricity	120.8	0.0116
Natural gas production	111.6	0.0332
GDP per capita	128.4	0.0008
R&D investment	139.3	0.0000
Steel scrap imports	151.3	0.0000

Table A2: Descriptive Statistics

Variable	Mean	Std. dev.	Min	Max
Steel production	1.056	1.580	0.000	6.223
Steel export	2.787	1.070	0.301	5.047
BOF steel production	3.659	0.814	0.778	6.088
EAF steel production	2.884	0.986	0.000	5.657
Steel use	3.194	0.815	0.477	5.866
Natural gas production	1.072	1.369	0.000	5.182
Iron ore production	0.614	1.423	0.000	6.313
Electricity generated	1.053	0.808	0.000	4.270
Metal. coke production	0.599	0.518	0.041	2.666
GDP per capita	3.871	0.542	2.443	5.241
R&D investment	7.633	1.299	0.000	10.23
Maritime transport cost	0.042	0.083	0.000	1.560
Steel scrap imports	2.544	0.985	0.000	5.031

Table A3: Determinants of Steel Export: Additional Control Variables (Fixed effects regressions, unbalanced panel)

	All countries (1)	Advanced countries (2)	Developing countries (3)	All countries (4)
LN steel use	-0.330***	-0.351***	-0.861***	-0.271**
	(0.0729)	(0.120)	(0.125)	(0.120)
LN iron ore production	-0.0180	-0.0314**	-0.0283	-0.00661
	(0.0124)	(0.0129)	(0.0282)	(0.0195)
LN electricity generated	0.523***	0.243**	1.250***	-0.156
	(0.0912)	(0.112)	(0.168)	(0.217)
LN metal. coke production	1.035***	0.740***	0.807***	0.909***
	(0.123)	(0.177)	(0.185)	(0.170)
LN GDP per capita	0.149	0.136	0.494**	
	(0.174)	(0.313)	(0.236)	
LN Steel scrap imports	0.0462***	0.0909***	0.0292	-0.00706
	(0.0153)	(0.0261)	(0.0202)	(0.0322)
LN nat. gas production				0.0694*
				(0.0382)
LN R&D investment				0.0111
				(0.0124)
Constant	2.517***	3.448***	1.715**	4.696***
	(0.629)	(1.303)	(0.805)	(0.511)
Observations	608	341	267	241
R-squared	0.532	0.359	0.693	0.397
Number of countries	32	16	16	15

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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