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**RESEARCH AND DEVELOPMENT, INNOVATION AND PRODUCTIVITY GROWTH IN THE  
STEEL SECTOR**

Filipe Silva;Anthony de Carvalho

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## FOREWORD

OECD Steel Committee delegates discussed a draft of this report at the Steel Committee meeting on 30 November and 1 December 2015. Delegates agreed to declassify the report in December 2015. Section 3.3 of this report has been released separately, in December 2015, as a short brief on environmental innovations that relate to steel entitled "Greening Steel: Innovation for climate change mitigation in the steel sector", and available at the OECD Steel website: <http://oe.cd/steeleny>.

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**RESEARCH AND DEVELOPMENT, INNOVATION AND PRODUCTIVITY GROWTH  
IN THE STEEL SECTOR**

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**ABSTRACT**

Investments in R&D activity and innovation could help the steel industry to lower its future capital requirements and operating costs, while also increasing yields and reducing resource and energy use. These investments would ultimately help the industry become more efficient and economically viable. This paper examines technological trends, innovation efforts and outcomes, as well as their implications for productivity in the steel sector. The analysis shows that investments into R&D were drastically reduced during the run up to the financial crisis but are slowly increasing. Results from an analysis of patent applications suggest that the direction of invention in steel-related technologies is turning towards climate change mitigation. However, a recent downward trend could be of concern given the environmental challenges ahead. The paper also explores firm-level productivity differences that unveil important challenges that may need to be addressed to ensure the sustainability of the steel sector. By providing a first look at innovation and productivity issues in the global steel industry, this paper also proposes possible avenues for future research.

Keywords: Steel; Firm performance; R&D investment; Innovation; Productivity

JEL Classification: L61; L250; O31; O32; D24

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## 1. Introduction

Technological advances and innovation have played a crucial role in the steel industry, helping to boost productivity growth through continuous improvements in production processes and the introduction of higher quality and value-added steel products. New casting techniques, more advanced steel rolling processes, and better monitoring and control systems, for example, have helped the industry to reduce the number of discrete steps in the production process. Product innovations have included steel products with better corrosion resistance, higher strength-to-weight ratios, and greater heat resistance. In some cases, the introduction of new technologies altogether has led to increased competition amongst producers with older technologies, leading to a reallocation of production and a more productive industry in the aggregate (Collard-Wexler and De Loecker, 2013).

Investments in Research and Development Activity (R&D) and innovation could help the industry to lower its future capital requirements and operating costs, while possibly also increasing yields and reducing resource and energy use. While this would ultimately help the industry become more economically viable, the industry's currently low level of profitability, its high debt, and difficulties in access to finance (OECD, 2015i) can act as significant barriers for investments in R&D and innovation.

This paper examines technological trends, innovation efforts and outcomes, as well as their implications for productivity in the steel sector. As part of the analysis, tracking patent applications helps cast light on major technological shifts and technological advantages, while also demonstrating how the industry has been focusing on improving its environmental performance. The paper also explores firm-level productivity differences that unveil important challenges that may need to be addressed to ensure the sustainability of the steel sector.

Given the current context facing the steel sector, understanding the nexus between innovation efforts, innovation outputs and productivity growth is particularly important for three main reasons. First, at the level of the firm steel companies face an increasingly competitive global market. Technological advantages and differentiated higher quality products can contribute to growth and increase profitability and competitiveness (OECD, 2015i). Innovation can help firms gain competitive advantages in higher-value segments of the steel market (de Carvalho and Sekiguchi, 2015) and contribute to upgrading in global value chains (OECD, 2015f).

Second, sectoral productivity can arise from a reallocation of resources towards the most productive firms (OECD, 2015g). In a context of excess global steelmaking capacity (OECD, 2015a), it is particularly important that policymakers ensure that markets can contribute to an efficient allocation of resources. This entails, for example, guaranteeing a level playing field — including between state and privately owned enterprises (OECD, 2012b) — removing (potentially) existing support to less productive units that can maintain or create economically inefficient capacity as well as removing other existing barriers to exit (and entry of new firms). Working together with the industry to foresee and alleviate any negative economic and social impacts that resource reallocation may bring about is also essential.

Third, rapidly increasing environmental challenges require new approaches and production processes that help mitigate climate change and contribute to a more efficient use of resources. The steel industry has often been subject to critique for its environmental performance. Even though many innovations have been made which help address environmental challenges, more investments in R&D, training, and other efforts need to be undertaken — by the industry in collaboration with governments — to ensure that breakthrough green(er) technologies in steel production can be expected in the years to come.

The results presented in this paper demonstrate that the steel industry has made important efforts to innovate even though there is still room for improvement, notably in terms of developing a breakthrough steelmaking technology that, while boosting productivity growth, could significantly improve the industry's environmental performance.

The remainder of the paper is organised as follows. Section 2 discusses the importance of investments in innovation, notably in terms of R&D and human capital, and describes the performance of the steel industry in this respect. Section 3 overviews innovation outputs in steel by first providing a historical overview of the development of steelmaking technologies, followed by an analysis of patenting activity that focuses on environmentally-friendly technologies and the efforts made by the steel industry to increase environmental performance. Section 4 presents evidence on the extent of economic efficiency in the steel industry, including a comparison with a selected number of industries using firm-level productivity data recently compiled by the OECD. The analysis of productivity distributions also feeds into a discussion about uneconomic/excess steelmaking capacity. Section 6 concludes and hints at some possible venues for further research.

## **2. Research and development activities in the steel sector**

Research and Development activity is one of the most important drivers of innovation together with investments in a broader range of intangible assets, from software and large data sets to designs, firm-specific human capital and new organisational processes (OECD, 2013b). Research and development efforts in the iron and steel industry are driven by the goal to improve the productivity of industrial processes (Laitner et al., 2001). Investments in R&D and innovation could help the steel industry to lower its future capital requirements and operating costs, while possibly also increasing yields and reducing resource and energy use.

Investments in innovation can be costly (OECD, 2009) and companies may find it difficult to obtain the necessary funds to perform R&D activities and implement innovations, in particular due to financial market imperfections (e.g. Hall and Lerner, 2010). In fact, financial constraints have been found to reduce the amounts invested in R&D and hamper innovation (e.g. Silva and Carreira, 2014), in particular when it comes to cutting-edge R&D activity (Czarnitzki and Hottenrott, 2011). In addition, private investment in R&D and innovation may be below a socially optimal level, mainly because returns are uncertain or the innovator cannot appropriate all the benefits. Investing in innovation is also risky, as many R&D projects will not result in an invention, and not all patent applications will be novel enough to receive a patent. Well-designed policies for the steel industry can play an important role in fostering investment in R&D and innovation (OECD, 2010a). The OECD has been working to compile information on innovation policy instruments that can help spur business innovation — see *The Innovation Imperative*, (OECD, 2015d). Recently the OECD, jointly with the World Bank, launched the Innovation Policy Platform, a web-based interactive space that provides easy access to knowledge, learning resources, indicators and communities of practice on the design, implementation, and evaluation of innovation policies.<sup>1</sup>

In the context of low profitability of the steel industry (OECD, 2015i; OECD 2015b), the amount of financial resources that are available to devote to innovation are particularly scarce. Nevertheless, the industry could accrue large long-term benefits from investments in the research and development of new technologies and improved production processes.

### ***2.1. R&D expenditures***

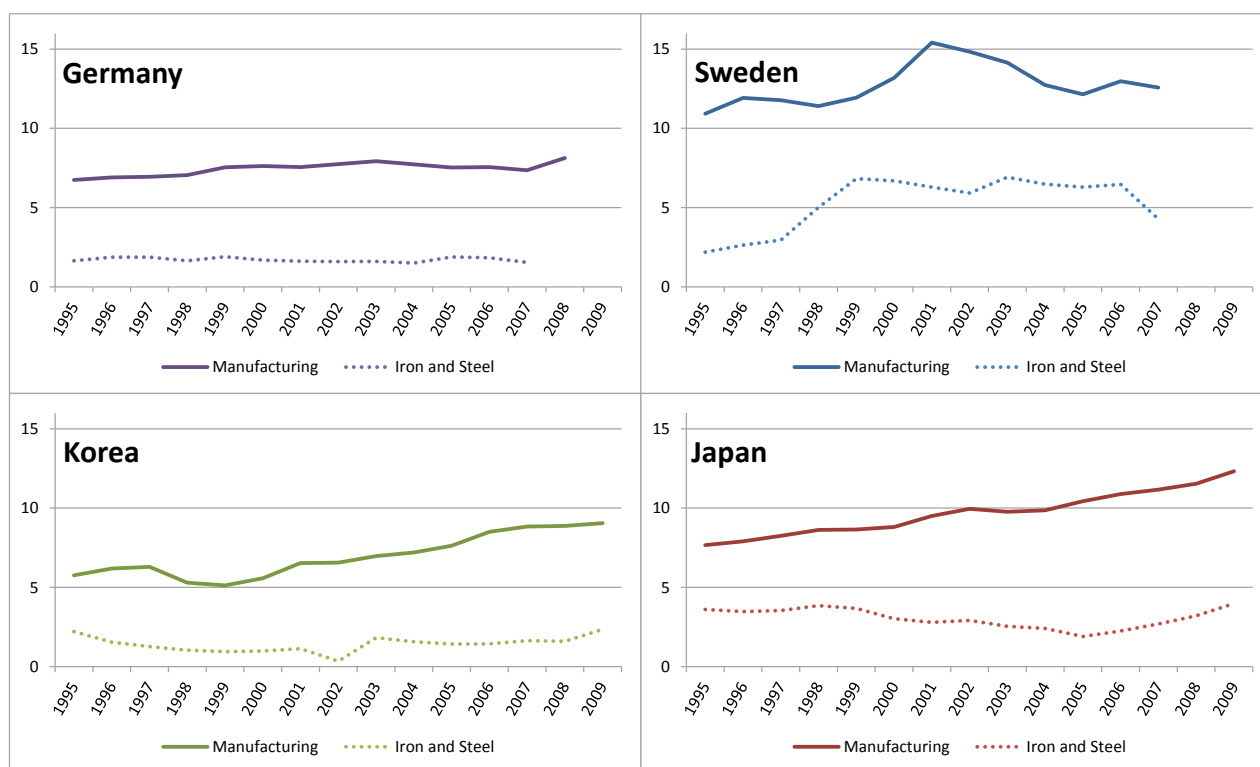
Levels of R&D expenditure and activity vary widely across industries. Recent work at the OECD that compares R&D intensity across industries classifies “Manufacture of Basic Metals” (i.e. iron and steel and non-ferrous metals) as a “medium R&D intensive industry” in a five-class R&D intensity classification

system (OECD, 2015e).<sup>2</sup> Investments in R&D in the steel sector are indeed relatively low when compared to other sectors. Figure 1 below compares R&D intensity in the steel industry with total manufacturing for a selected number of economies. Between 1995 and 2009, R&D intensity in the steel industry was lower relative to overall manufacturing in these economies.

Firm-level data from the commercial information provider Factset also show that the share of investments in R&D by publicly traded companies is considerably lower in steel, when compared to other industries. Figure 2 compares the average R&D expenditure of companies in selected industries between 1992 and 2014. Expenditures by steelmaking companies are amongst the lowest, comparable to R&D investments made by companies in the shipbuilding industry, but much below R&D spending in chemicals or plastics.<sup>3</sup> This is visible both in terms of the share of R&D in total assets of the company (Panel A), but also in R&D relative to physical capital investment (Panel B), across the 1992 and 2014 period.

**Figure 1. Comparison of R&D intensities in steel and total manufacturing**

R&D expenditures divided by gross value-added, selected economies 1995-2009



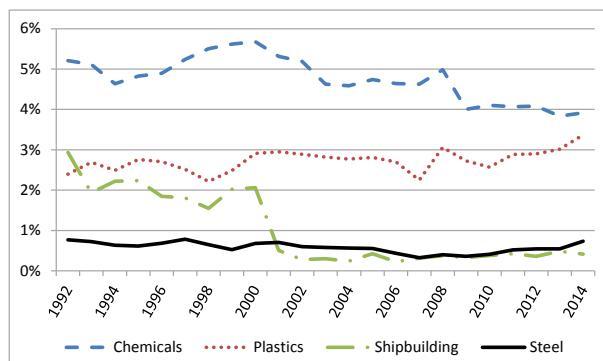
Notes: R&D intensity is calculated as R&D expenditures divided by gross value added of the steel industry in each economy. The steel industry is defined using the international industry classification system ISIC Rev. 3 Manufacture of basic Iron and steel (C271). Economies are selected on the basis of data availability.

Source: OECD's Structural Analysis (STAN) and Analytical Business Enterprise Research and Development (ANBERD) databases.

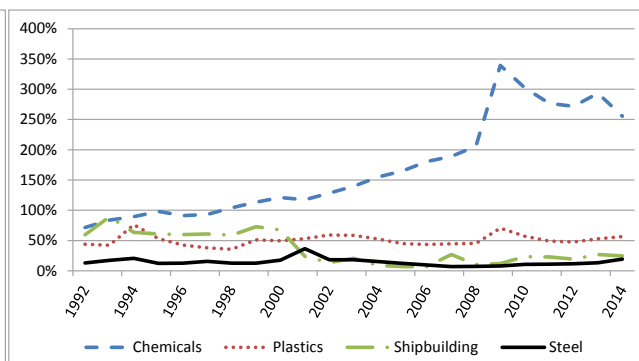
**Figure 2. R&D investments by steelmaking companies**

World average, publicly traded companies, 1992-2014

A. As a percentage of total assets



B. Relative to capital expenditures



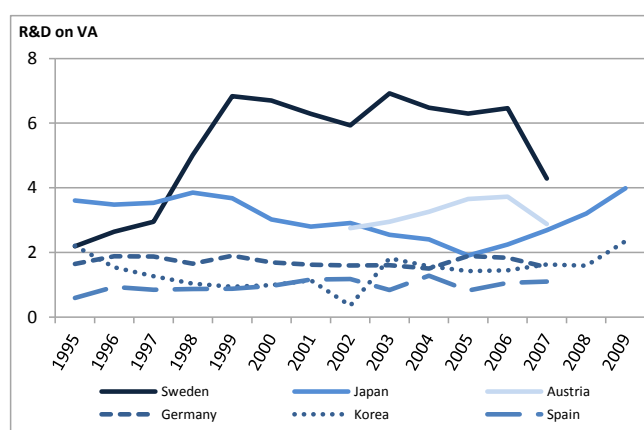
Note: Please refer to OECD (2015i) for a detailed description of the industry classification used.

Source: OECD calculations based on data from Factset. A detailed description of the underlying dataset is provided in OECD (2015i).

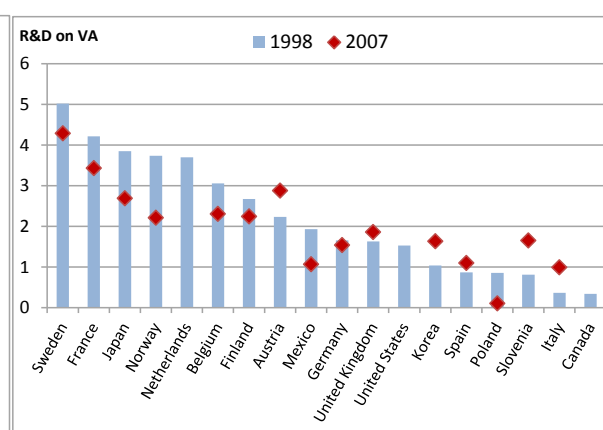
Investments in R&D in the steel sector vary significantly across economies. Figure 3 below compares R&D intensity (R&D expenditure divided by value-added) across selected economies for which comparable data are available for the period 2001-2009.<sup>4</sup> Panel A on the left shows the evolution of R&D intensity while panel B shows the difference in R&D intensity between 1998 and 2007. These data suggest that R&D intensity declined between 1998 and 2007 for several large steelmaking economies that historically exhibit high levels of R&D intensity. However, where available, data for 2008 and 2009 suggest an inversion of this trend. The latest information on absolute expenditure in R&D in the steel sector for the period 2011-2013, suggests that investments in R&D across several economies are increasing. For example, R&D investment in China and Korea has increased about 50% and 10%, respectively.

**Figure 3. R&D intensity in the steel industry for selected economies**

A. Evolution of R&amp;D intensity, 1995-2009



B. R&amp;D intensity in 1998 and 2007



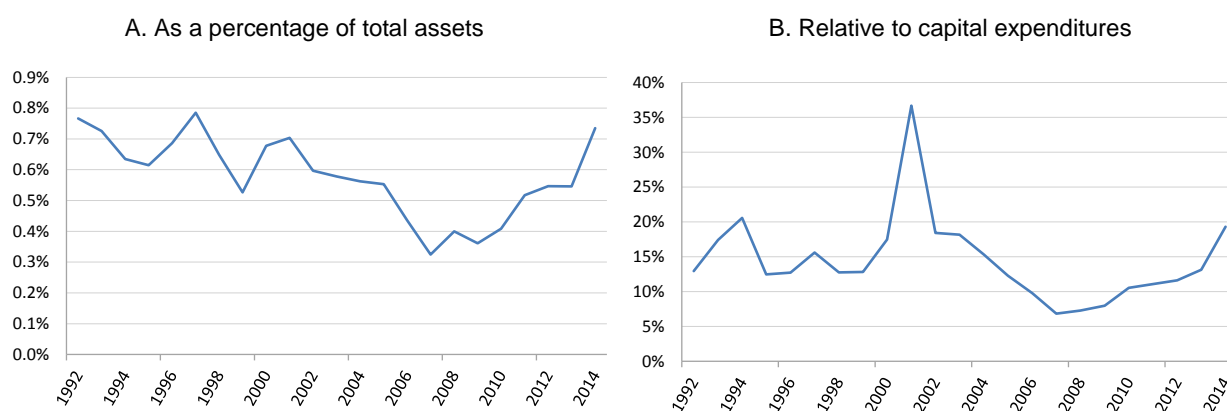
Notes: R&D intensity is calculated as R&D expenditures divided by gross value added of the steel industry in each economy. The steel industry is defined using the international industry classification system ISIC Rev. 3 Manufacture of basic Iron and steel (C271). Economies are selected on the basis of data availability. In panel B, data are not available for 2007, thus the latest available year was used as follows: France (2006), Finland (2005), United Kingdom (2006), Poland (2006), Slovenia (2006).

Source: OECD's Structural Analysis (STAN) and Analytical Business Enterprise Research and Development (ANBERD) databases.

Firm-level data from the commercial information provider Factset also show that the share of investments in R&D by publicly traded steelmaking companies have been increasing recently (Figure 4). However, the amounts devoted to R&D had been decreasing during the run up to the financial crisis (2002-2007). This is particularly puzzling because during this period steelmaking companies were performing rather well, experiencing rapid demand growth and achieving high profit levels.<sup>5</sup> In fact, OECD work looking into the financial situation of steelmaking companies (OECD 2015i) shows that free cash-flow had reached its highest levels during this period.<sup>6</sup> As such, it suggests that at the time, the average steelmaker should have had room of manoeuvre to increase, or at least maintain their levels of investment in R&D. This might be explained by the rapid expansion of capacity that began in the early 2000s, which increased total assets relative to R&D investments.

**Figure 4. R&D investments by steelmaking companies**

World average, publicly traded companies, 1992-2014



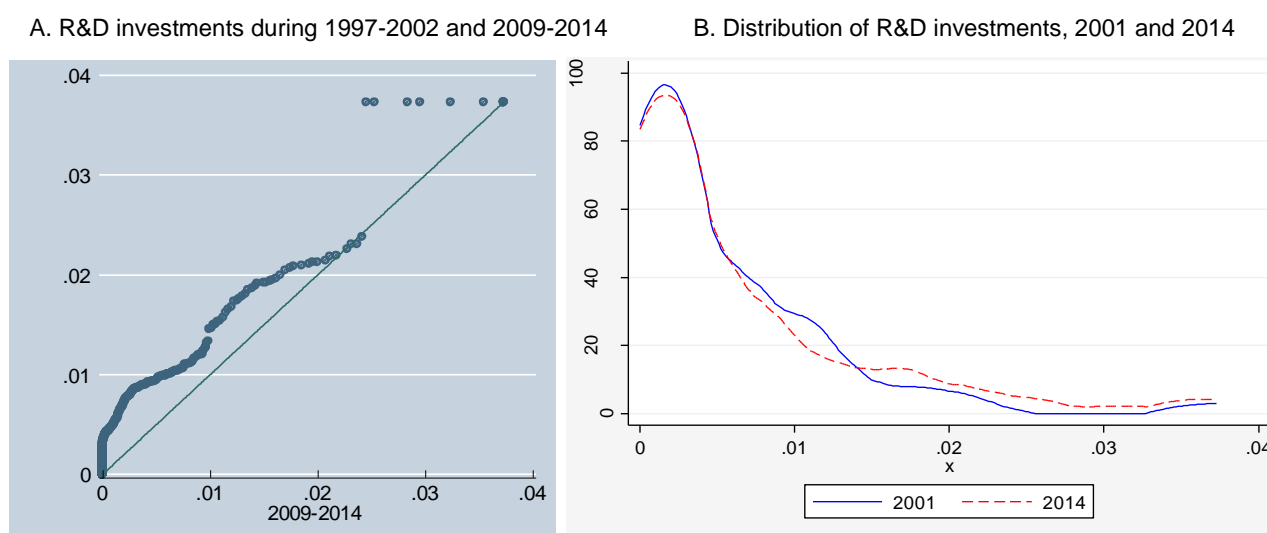
Source: OECD calculations based on data from Factset. A detailed description of the underlying dataset is provided in OECD (2015i).

In other words, steelmaking companies were using their returns to invest in capacity and quantity, rather than in innovative products and quality. Perhaps, expectations of tighter environmental regulations together with an extremely competitive market for commodity steel products, might be encouraging firms to invest more in new and cleaner processes as well as differentiated, customised and high quality new products. For example, R&D has been a key element of the success of Voestalpine Group, a technology leader in special rails, turnout technology, and related services for high-speed, heavy-haul, and urban traffic. As part of Voestalpine's strategy, a number of long-term R&D partnerships are established with strategic customers and research institutions and universities worldwide.<sup>7</sup>

The financial crisis may have had a significant impact upon firms' ability to invest in R&D, but it appears that R&D investments are recovering to higher levels. Figure 5 below provides a visual comparison of the distribution of R&D investments on total assets in selected periods. Panel A compares the distribution in two periods (1997-2002 and 2009-2014). The chart can be interpreted based on the diagonal line: more (less) dots above the diagonal line mean that R&D investments for each company were larger (smaller) during the 1997-2002 period relative to 2009-2014. Panel B shows the distribution of R&D investments in 2001 and 2014 — i.e. up to a given value  $X$  of R&D investment on assets (horizontal axis) the area below each of the lines (corresponding to 2001, or 2014) provides the share of companies with R&D on assets up to  $X$ . This means that the more (less) area there is below the curve on the right side of the chart, the higher (lower) the R&D investments were — also, the higher the curve for a given interval on the horizontal axis (R&D on assets), the higher the percentage of companies with R&D on assets in that interval. For example, looking at the interval on the horizontal axis between 0.01 and 0.012 shows that there was a higher percentage of companies with R&D on assets between 1% and 1.5% in 2002 compared to 2014.

Even though there is no clear-cut differences in R&D investments between the selected years 2001 and 2014 (Panel B), between 2009 and 2014 steelmaking companies invested much less in R&D than they did in 1997-2002 (Panel A). When compared to the previous steel crisis in 1997-2002 (see OECD, 2015i), steelmaking companies invested much less in R&D during the 2009-2014 period than they did during the previous crisis. Interestingly, the reduction in R&D investments between the two periods took place in steelmaking companies across the board. This is visible in panel A, where all companies (denoted by dots) are above the diagonal line — i.e. the distribution in 1997-2002 dominates the distribution in 2009-2014. This is relevant as R&D investments can be an important driver of productivity growth (OECD, 2013d) and are likely to be important for the steel industry to move towards increased energy efficiency and reduce CO<sub>2</sub> emission in the future (OECD, 2010b; OECD, 2012a).

**Figure 5. Comparison of R&D investment levels between periods**



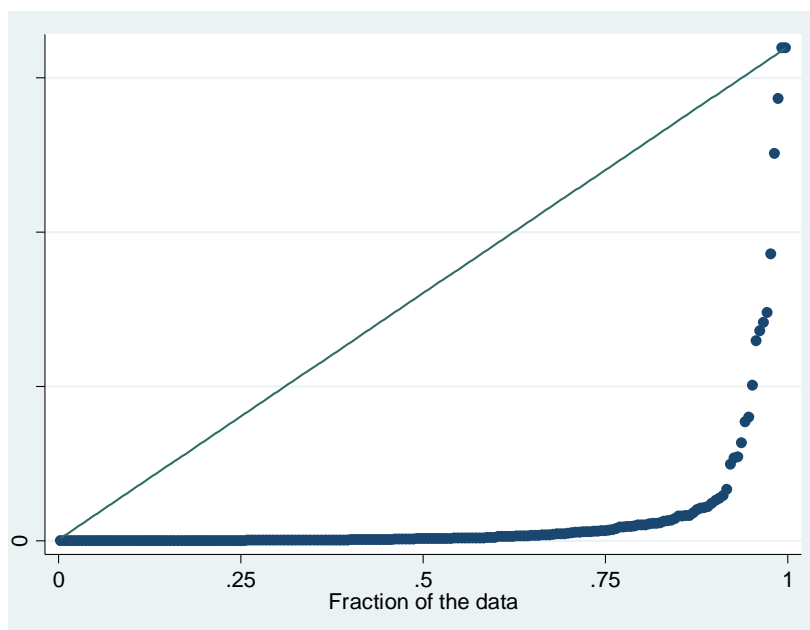
Notes: Two approaches are used to make the comparisons. Panel A plots two distributions using a quantile-quantile plot. After ranking each distribution, this chart contrasts values in the same quantile. Therefore, values above the diagonal ( $y=x$ ) indicate that the distribution of R&D investment on assets for the period 1997-2000 dominates the distribution of the same variable for the period 2008-2012. The reverse is true for values below the line. Panel B plots the distributions of two specific years (2012 versus 2001) using charts with the kernel density estimate. The kernel density estimate gives an approximation of the probability density function of a given distribution — up to a given point  $x$  in the horizontal axis, the area under this function provides the percentage of observations that have values that are lower or equal to  $x$ . The total area below the curve for each year equals one. Data refer to investments in R&D by publicly traded companies. See OECD (2015i) for further details on the dataset used.

Source: OECD (2015i) based on data from Factset.

Firms' strategies towards R&D and innovation can be very different. There is typically a large number of firms that do not engage in R&D, either because they lack the necessary facilities, scale or finance, or simply because of strategic reasons. For example, while some firms may choose to invest significantly in R&D, others may prefer to ensure that they have the appropriate resources and capacities (e.g. human capital and skilled labour, organisational structure, ICT technologies, etc.) that allow for a rapid adoption of new processes developed elsewhere. The case of the steel industry is not different.<sup>8</sup> Figure 6 below shows the distribution of R&D expenditure in 2012, where the quantiles of the distribution are plotted against the fraction of the data (companies ranked by their R&D expenditure). It is clear that only a very limited number of steel companies invested in R&D. Roughly 75% of the companies in the sample do not engage in R&D activities, while a small number of companies (those on the right side of the chart) invest heavily in R&D. Table 1 below lists the top 10 R&D performing companies, featuring Baoshan Iron & Steel Company, Nippon Steel & Sumitomo Metal and POSCO as the three companies that spent more in R&D during 2014.

**Figure 6. R&D investments by steelmaking companies**

Distribution of steel companies in 2014



Notes: The chart plots the R&D distribution using a quantile plot. In the horizontal axis, companies are ranked according to their R&D investments (in USD million), which is given by the vertical axis. Data refers to investments in R&D by publicly traded companies. See OECD (2015i) for further details on the dataset used.

Source: OECD calculations based on data from Factset. A detailed description of the underlying dataset is provided in OECD (2015i).

**Table 1. Steelmaking companies with highest R&D investments in 2014**

Rank	Name	Headquarters	R&D (USD million)
1	Baoshan Iron & Steel Company	China	638.6
2	Nippon Steel & Sumitomo Metal	Japan	573.2
3	POSCO	Korea	501.9
4	Shanxi Taigang Stainless Steel	China	372.0
5	JFE Steel	Japan	295.7
6	Hebei Iron and Steel	China	282.9
7	Kobe Steel	Japan	272.2
8	ArcelorMittal	Luxembourg	259.0
9	Gansu Jiu Steel Group Hongxing Iron & Steel	China	201.4
10	voestalpine AG	Austria	159.8

Note: Data refers to absolute R&D expenditures (in USD million) by publicly traded companies. Please note that high R&D expenditures do not necessarily translate into high R&D or innovative performance. See the Annex for further details.

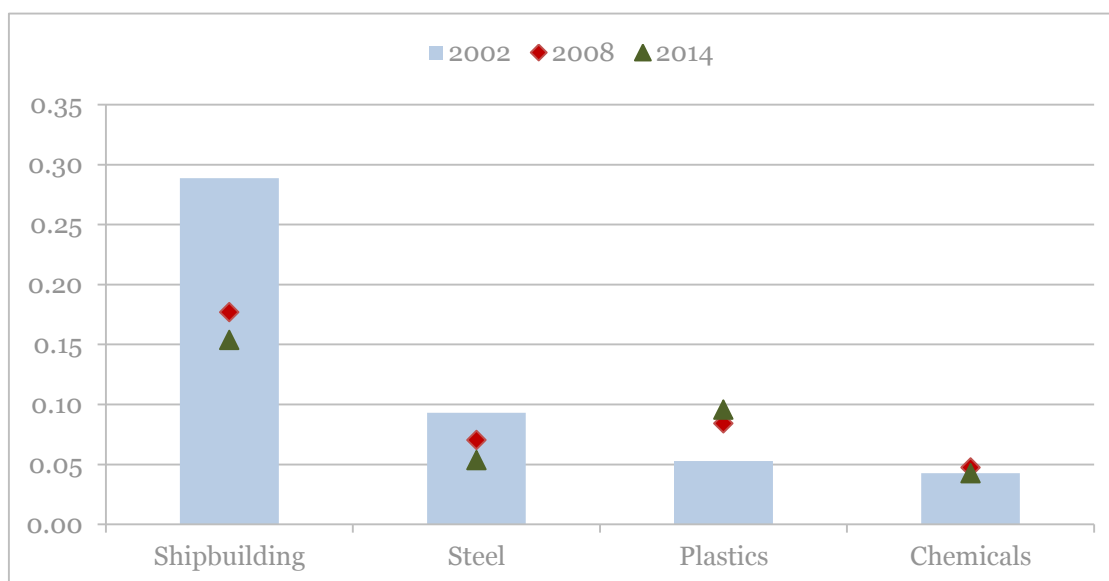
Source: OECD calculations based on data from Factset. A detailed description of the underlying dataset is provided in OECD (2015i).

However, the extent of concentration of R&D investments in a small number of companies does not seem to be particularly high in steel relative to other heavy industries. Bearing in mind that different sectors exhibit distinct industrial structures as well as different R&D intensities (as described above), a possible approach to compare the concentration of R&D investments in steel to other industries is to construct a Herfindahl index. This index provides an indication of the degree of concentration of R&D

investment, where values close to unity (zero) indicate a very high (low) concentration of R&D investments. Figure 7 depicts a Herfindahl index for R&D investments in selected industries in 2001, 2008 and 2014. Data presented in the Figure suggest that concentration of R&D investments was, in 2014, relatively lower in steel than in other sectors such as shipbuilding or plastics. In addition, it suggests that R&D investments in the steel industry have become less concentrated over the past 13 years.

**Figure 7. Concentration of R&D investments**

Selected industries, 2002, 2008 and 2014



*Notes:* The chart plots the Herfindahl index for R&D investments in selected industries. The index varies between zero and one. Values close to unity (zero) indicate a very high (low) concentration of R&D investments by publicly traded companies. Data refers to investments in R&D by publicly traded companies. See OECD (2015i) for further details on the dataset used.

*Source:* OECD calculations based on data from Factsset. A detailed description of the underlying dataset is provided in OECD (2015i).

Recent OECD work that focused on the financial performance of the steel industry (OECD, 2013a) suggested that there is a negative correlation between R&D investments and profitability for steelmaking companies. However, the analysis focused on short-term impacts and did not take into consideration that this type of investment usually entails a long period of time until profits can be reaped. In addition, R&D investments are not easy to use as collateral for obtaining external finance. Therefore, it is reasonable to expect that, in the short term, R&D efforts can take a toll on profits. This means that, in the short-term, incentives to invest in R&D can be very low. However, long-term gains in terms of productivity, environmental performance, and ultimately long-term financial performance and competitiveness can be very high.<sup>9</sup> A deeper understanding of the relationship between R&D efforts and long-term profitability and competitiveness in the steel industry is not in within the scope of this paper but could be considered in future work.

In steel, some past experiences have nevertheless shown that the amount of resources allocated to research and development may not be the main determinant of economic performance (e.g. the case of the minimill in the United States); instead, it is how effectively these R&D resources are utilised which is of importance. In addition, the use of innovations made elsewhere can also promote noticeable efficiency gains in steel (technology diffusion). For example, despite cutbacks in R&D resources by some steelmakers in the 1980s, the research units of these firms became much more productive by integrating more closely with production plants, suppliers and customers (Fruehan et al., 1999). As another example,

the adoption of thin-slab casting techniques by minimills, which traditionally had only modest R&D activities, has led to significant gains in productivity and profitability in the past.<sup>10</sup>

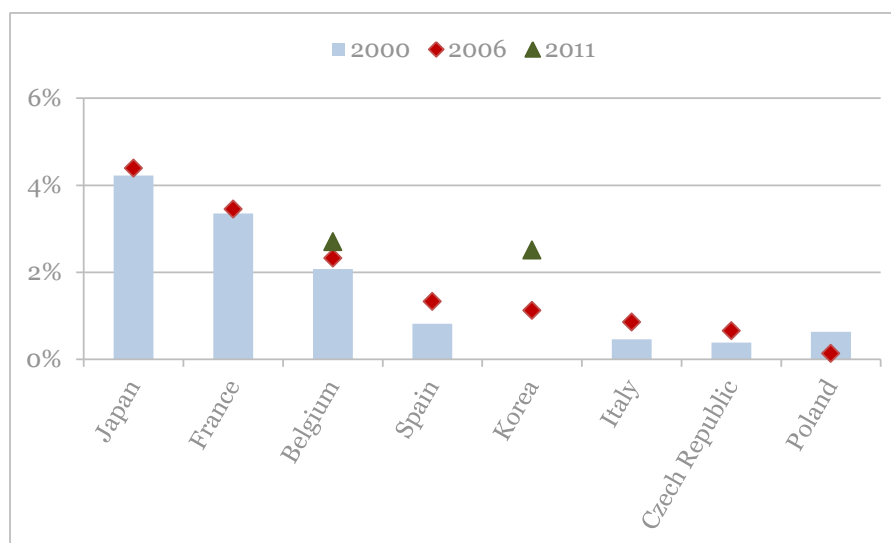
Overall, despite the financing challenges faced by the steel industry (OECD, 2015i), it is important that sufficient resources are devoted to R&D activity. Research and development investments can be an important driver of productivity growth (OECD, 2013d) and are likely to be important for the steel industry to move towards increased energy efficiency and reduce CO<sub>2</sub> emission in the future (OECD, 2010b; OECD, 2012a). Priority should be given to investment in quality rather than quantity, notably in the current context of global excess steelmaking capacity.

## 2.2. Labour, R&D personnel and training

R&D efforts build upon the human capital available in companies (OECD, 2013b), more specifically on firm employees that are engaged in R&D activities. In 2006, the share of R&D personnel in total employment in the steel industry exceeded 4% in Japan and 3% in France (Figure 8). The limited available data suggest that the number of employees devoted to R&D activities may have increased during the 2000s. For example, both in Belgium and Korea, the percentage of R&D personnel in the steel industry was higher in 2011 than before the financial crisis.

**Figure 8. Percentage of R&D personnel in the steel industry**

Selected economies, 2000, 2006 and 2011



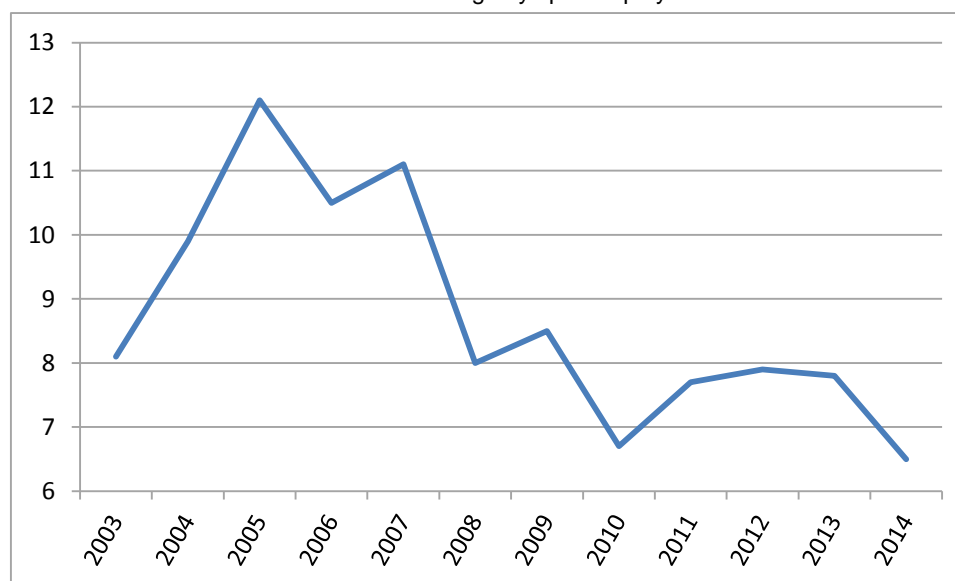
Note: The Steel industry is defined using the international industry classification system ISIC Rev. 3 Manufacture of basic iron and steel (C271). Percentages are computed as the ratio of full-time equivalent personnel on R&D activities to total number of employees in the industry for each economy. Research and development personnel include all persons employed directly in R&D activities and therefore cover technicians and support staff as well as researchers. Economies are selected according to data availability.

Source: OECD SDBS Structural Business Statistics database.

The ability to innovate, assimilate and adopt new technologies does not depend solely on highly skilled R&D personnel. The right mix of skills is key to a company's success, but can be challenging to attain — especially when labour market rigidities may exacerbate skills mismatches. Education and training are fundamental for steel companies to strive, innovate and increase productivity and efficiency, (OECD, 2015d). New technologies can be easier to adopt and implement if companies have a skilled and well-trained labour force (OECD, 2013b). Recent indicators of employee training compiled by the World Steel Association (2015) suggest that the number of training days per employee was substantially reduced

after the financial crisis (Figure 9). On average, each employee received 6.5 days of training in 2014, which is below 11.1 days observed in 2007. It is important that employee training continues to be supported, amidst the current challenging financial situation that steelmaking companies face. For example, using new information and telecommunication technologies — massive open online courses and other open educational resources (see OECD, 2014b) — could provide cost-efficient solutions for the provision of training. As an example, the Steel University, an initiative of the World Steel Association, provides a wide range of training tools including freely available online courses and simulators.<sup>11</sup>

**Figure 9. Employee training**  
Number of training days per employee



*Note:* Employee training includes both production and non-production facilities. The data were obtained through a survey conducted by the World Steel Association that covered 147 companies, representing about 55% of global crude steel production in 2014. Further information on this indicator available at [www.worldsteel.org/steel-by-topic/sustainable-steel/social/training.html](http://www.worldsteel.org/steel-by-topic/sustainable-steel/social/training.html).

*Source:* World Steel Association (2015).

It is important that while the steel industry ensures that it has a well-trained and skilled labour force, policy in different countries contributes to a better alignment of education programmes and the skills needed by the industry.<sup>12</sup> In addition, increased industry-university collaboration is also crucial to ensuring a highly skilled labour force, sharing the costs of innovation, while leveraging on the research expertise of universities and other higher education institutions.<sup>13</sup> However, the development of industry-university collaboration projects is challenging and usually firms struggle to find their university counterparts and *vice-versa*. Systematic information on the extent of these collaborations in steel and other sectors is scarce. As an example, in Turkey significant collaborative efforts to innovate are being made by the industry and academia and include the first “Iron & Steel Institute” established in 2011 at Karabuk University, as well as a new research centre at the Istanbul Technical University, a joint venture with the Turkish Steel Exporters’ Association.<sup>14</sup>

Industry-government collaboration is an essential component of a well-functioning innovation system (see e.g. OECD, 2013d). In Sweden for example, the Swedish Steel Producers Association has developed a strategic research and innovation agenda (National Strategy for Metallic Materials) for the steel sector and the Swedish innovation agency (VINNOVA) supported and funded the implementation of a Strategic Innovation Program based on the steel industry’s strategic agenda.<sup>15</sup>

### 3. Inventions and new technologies in steel

A predecessor to the Bessemer process was already used in China as early as the second century BC (World Steel Association, 2012). There can be a significant time lapse between the idea, the invention of a new technology, the corresponding patent application and grant, the first implementation and the diffusion of the technology across plants companies and countries. The innovation process entails not only breakthrough technologies but also incremental innovations that help refine the original invention. In the case of the steelmaking process, most of the innovations have been incremental in nature over the last few decades, since the introduction of methods during the 1960s that radically changed the way steel is produced. Sometimes a number of related inventions are also needed before an idea can be feasibly turned into an invention and implemented.<sup>16</sup> Box 1 provides an illustration of this process using the example of the development and implementation of the basic oxygen furnace technology.

In addition, in the case of steel technologies, high entry barriers, the industrial structure, high sunk costs and high barriers to exit result in a relatively high technological path dependency that contributes to a considerable lapse of time between innovations, the introduction of the technology and technology dissemination (D'Costa, 2003). For example, the change in technological paradigm with the replacement of open hearth furnaces (OHF) by basic oxygen furnaces (BOF), and later the introduction of the electric-arc furnace (EAF), have been particularly challenging for established firms at the time of the technological shifts. Incumbents in the steel market had already made substantial investments in their OHF plants. In contrast, latecomers found it easier to leapfrog and adopt the new technology. These advances at the technological frontier are important drivers of industry restructuring and can result in higher productivity growth (Collard-Wexler and De Loecker, 2015).

#### Box 1. BOF technology: from idea to diffusion

The case of BOF technology is particularly interesting. The idea of injecting pure oxygen to remove the impurities in molten iron, while not affecting its malleability and strength, was already foreseen by Henry Bessemer in 1856. However, limitations such as the availability of cheap pure oxygen and the damaging effect of the inevitable blast upon the converter's tuyeres and refractory lining, resulted in the dissemination of a competing technology that produced higher quality steels, the open earth furnace (OHF) developed by Carl Siemens and later applied by Pierre-Émile Martin in 1865.

In fact, implementing the idea of injecting pure oxygen into the steelmaking process would require a number of process innovations before (e.g. the Linde-Frinkl process for producing bulk oxygen of 99% purity at very low cost). The final breakthrough in the development of the oxygen process by Schwarz, Miles, and Durrer took place in the late 1930s, and culminated in a patent application in 1939, later issued as German Patent No. 735,196, on July 3, 1943. Robert Durrer would then conduct the first experimental top-blown pure-oxygen test later in 1948.

The Austrian company VOEST made the final refinements to the technology and introduced the process in 1950 and started large scale production in 1952. Interestingly, the innovation was introduced and applied "by a firm that was less than one-third the size of a single plant of the United States Steel Corporation" in a region ravaged by a recently fought war. The dissemination of the new technology to the United States only started to take form during the mid-1960s.

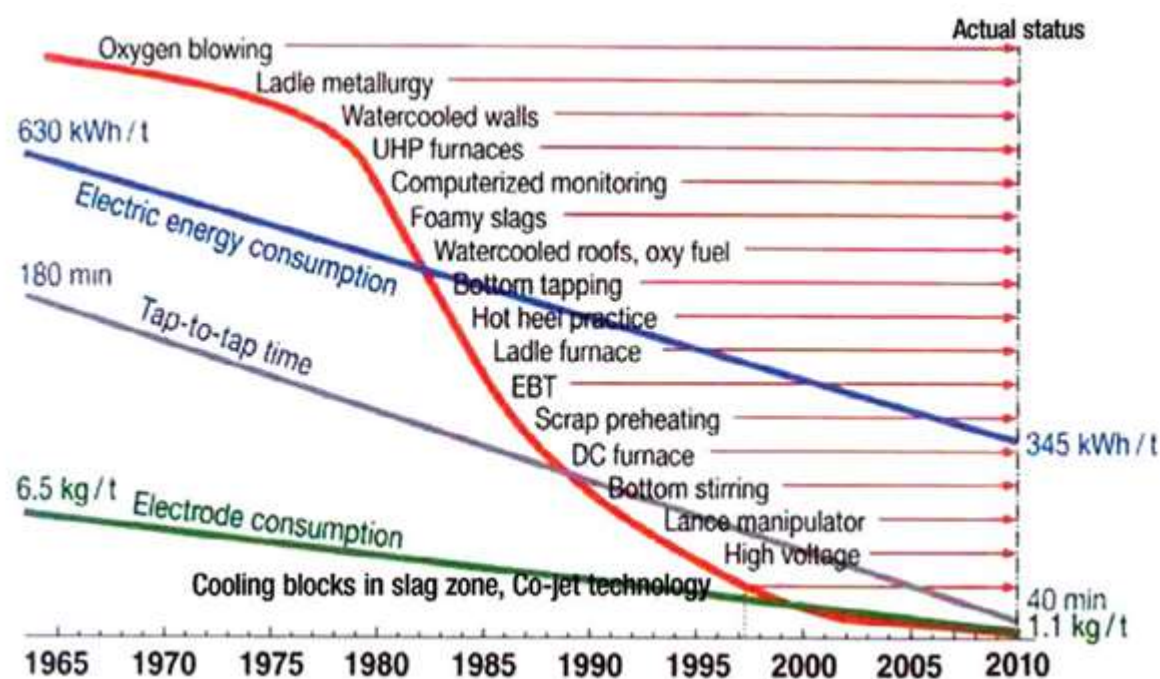
*Source : Adams and Dirlam (1966).*

New technologies can nevertheless imply lower capital requirements, thus reducing the opportunity costs of shifting from an older technology. Moreover, the maintenance costs for the older technology can be significant. For example, the capital requirements (measured as cost per ton) of a minimill have been found to be almost half of those of an integrated producer. In addition, the cost of a blast furnace reline can sometimes be close to the cost of setting up a new minimill (D'Costa, 2003).

Incremental innovations are very important. Figure 10 below shows how different improvements to the EAF technology through time went hand in hand with substantial gains in terms of energy efficiency and productivity.

The technologies that one can see in a modern steel plant today are therefore the result of the accumulation of experience and knowledge over many years and decades.

**Figure 10. Incremental innovations in EAF technology**



Note: The figure depicts the gains, in terms of productivity (tap-to-tap time) and energy efficiency (electric energy and electrode consumption), in the EAF process through time (horizontal axis) since the 1960s, achieved with different incremental innovations (projected on the vertical axis). The descending curve is a mere illustration of the reduction in inputs (energy and time) needed to produce a tonne of steel.

Source: Emi (2015).

### 3.1. An historical overview of steelmaking technologies

For more than 3 000 years the human race has strived to find the most efficient and economic methods of converting iron ore, through the application of energy and various techniques, to usable metals. As discussed in Box 1, two major technical advances in this long history occurred in the middle of the 19<sup>th</sup> century, when Henry Bessemer invented the oxygen steel converter and the Siemens brothers of Germany (with improvements made by Pierre-Émile Martin in France) invented the open hearth, or Siemens-Martin, process. These technological advances laid the foundation for the mass production of steel.

Innovations in the steel industry since then have been pursued at each stage of the production process, including ironmaking, steelmaking, and finishing (casting, rolling and coating). Together with the changing demands of steel consumers, improved production processes have supported the continuous innovation of steel products with superior qualities. The sources of these process and product innovations include in-house R&D laboratories, joint ventures with other steel companies (both domestic and international), innovations by suppliers, and collaboration with universities (Fruehan *et al.*, 1999). Improvements can include lower capital costs and operating costs, increased yields, and reductions in resource and energy use. Some innovations may be driven by one goal, but also generally include beneficial impacts on other aspects of a production process.

The discussion above suggests that a recurring motive for investing in R&D is to develop technologies that minimise the number of fixed assets in the steel mill. Doing so reduces invested capital, working capital requirements and operating and maintenance costs. Taking an extremely long-term perspective, one might envision R&D activity and innovations eventually leading to a production process involving much fewer pieces of machinery that make and finish the steel in a limited number of steps. Investing in product innovations, on the other hand, allows steelmakers to stay ahead of their competitors by offering sophisticated products to meet the more stringent requirements of steel-using industries, thus promoting gains in market share and profitability.

### 3.1.1. Overview of Process Developments

One of the main drivers of past process development activities has been the desire to reduce the number of fixed assets in steel mills in order to achieve lower capital requirements and operating costs. In what follows, examples of major technological advances occurring in the ironmaking, steelmaking, and finishing processes are presented.

#### Direct Reduction of Iron

Direct reduction methods (DRI), where solid iron products are produced from iron ore using natural gas (sometimes coal) as the reductant, date back to the 1950s. DRI production occurs mainly in areas close to abundant sources of natural gas and rich iron ore, and most of this production is used for on-site, or captive, consumption (Stubbles, 2007).<sup>17</sup> The several processes for DRI production that have been commercialised since the 1970s (*e.g.*, Midrex, HyL I, II and II, Fior, FASTMET, and Circored) offer viable alternatives to the traditional blast furnace ironmaking route. However, technical problems and high natural gas prices had, until more recently, limited DRI's share in world pig iron production. Research efforts have been directed at producing better quality iron input, including the use of fine ores, and ways of integrating DRI production with other steps in the steelmaking process (Nill, 2005). Recently, the use of DRI processes has been rapidly increasing (Midrex, 2013).<sup>18</sup>

#### Smelting Reduction Technologies

A number of research and development efforts focusing on the production of liquid iron directly from coal and iron ore fines or concentrate began in the mid-1970s. The major drivers of R&D in this field included lower capital costs and opportunities to process cheaper coals (Luiten *et al.*, 2006). The elimination of iron agglomeration plants also promised lower costs. Another advantage of smelting reduction is that it eliminates the pollution associated with coke ovens. Corex is the most commercially advanced of these smelting processes, with the first plant beginning production in 1989. After a protracted development process, the first commercial HIs melt plant started up in Australia in 2005.

Research and development in smelting reduction technologies lost steam in the 1990s, as several integrated producers stopped their research efforts altogether. According to Luiten *et al.* (2006), this

reflected factors such as the reduced threat that coke ovens and blast furnaces would have to be replaced (*e.g.*, since past improvements had extended their lifetimes) and the fact that many steelmakers felt there was less of a need for new ironmaking capacity. Many minimills and mining companies are still interested in the process, however, mainly due to the flexibility in the types of coal that can be used.

### Basic Oxygen Furnaces

Basic oxygen furnace (BOF) steelmaking emerged in the early 1950s, and displaced the Bessemer and open hearth processes in the decades that followed. Since the 1960s, virtually all the new integrated mills have been equipped with basic oxygen furnaces (Nill, 2005), with only a few exceptions in the CIS region.<sup>19</sup> The BOF process produced large efficiency gains, as the time required to convert iron into steel was shortened significantly, though it allowed less usage of scrap compared to its predecessors. Numerous development efforts since its introduction, including process monitoring and control, slag formation control, and experimentation with oxygen lance configurations, have led to continuous incremental improvements which have further improved the productivity and efficiency of basic oxygen steelmaking significantly (Manning and Fruehan, 2001). BOF is currently the major technology in steelmaking in the world. According to data from the World Steel Association, the share of BOF in crude steel production has increased from 34% in 1970 to 71.9% in 2013.

### Electric Arc Furnaces

Since the BOF process requires considerably less scrap than open hearth production, the rise of the BOF and the concomitant decline of the open hearth process in the post-World War II period meant greater availability and lower prices of scrap, which created greater opportunities for growth in scrap-based steelmaking (Manning and Fruehan, 2001). Therefore, although scrap-based electric arc furnace steelmaking was developed and commercialised already in the late 1800s, its diffusion occurred at roughly the same time as the BOF process, namely in the 1960s and thereafter. In their earlier days, EAFs were used primarily to produce small volumes of specialty steels.

The commercialisation of continuous casting methods suitable for EAF plants allowed these plants to gain considerable market share over integrated mills decades ago. EAF steelmakers have implemented, adapted and optimised processes very effectively and have innovated in areas including scrap substitutes and electric furnace improvements (Fruehan et al., 1999). The efficiency, feedstock flexibility and environmental advantages of EAFs make investing in them interesting options, especially given existing and likely future carbon emission regulations and growing steel scrap reservoirs (AMM, 2013). EAF technology is becoming increasingly important in particular in the NAFTA, partially due to the shale gas revolution, and in emerging economies with abundant and cheap natural gas resources.

### Casting

The process of casting involves the transformation of liquid steel into a solid state for shaping to the final product form. Before the advent of continuous casting in the 1960s, casting was a discontinuous process entailing the pouring of crude steel into permanent moulds or ingots. Continuous casting, where steel is poured directly into a casting machine to make the required shape, lowers unit energy costs since primary and intermediary rolling mills and some reheating furnaces are not needed. As a result of the enhanced productivity from continuous casting, it is nowadays the commonly used method for steel production globally.<sup>20</sup> Since the mid-1970s, considerable R&D efforts have been directed towards developing a process that would allow steel to be cast as close to the shape of the finished product as possible, so-called “near-net-shape casting”.

A recent development is thin-slab casting, which reduces the thickness of slab to 50 to 60 mm from the 200 to 300 mm thickness produced by early conventional slab casters. Less commercially proven technologies include near-net-shape strip casters (10-15mm thickness) and thin-strip casters, which can cast strip with thicknesses reaching as little as 1mm. For long products, research in rod, wire and section casting technologies may eventually remove the need for some primary rolling stages. Considerable development work is also being conducted to develop technologies that supplement casting, including electromagnetic applications to control fluid flow, advanced vision systems to detect defects in the steel product, liquid steel temperature control in the mold and tundish, and advanced ceramics for clean steel production (U.S. Department of Energy, 2001). Research is also being conducted on innovative filtering techniques to prevent inclusion particles from entering the casting machine.<sup>21</sup>

## Rolling

Semi-finished steel products from the caster undergo significant further processing and treatment. The steel produced and cast in the meltshop into semifinished shapes is processed into the desired shape by hot and cold rolling. Development efforts in this area have been spurred by the desire to reduce operational costs, minimise yield losses, increase productivity and improve product quality. Technological advances have centered on increased rolling speeds, greater equipment integration, and longer roll lives due to less wear and tear, among others.

## Coating

Coated steels have been developed in response to demand for greater corrosion resistance. Developments in processes such as electrogalvanizing, which bonds zinc to steel electrochemically, have improved the coating and corrosion resistance of many steel products (Fruehan *et al.*, 1999). Much collaboration between steelmakers and vehicle manufacturers is taking place to develop coatings with enhanced wear resistance and improved adhesive qualities, self-healing properties, and properties that reduce defects from cutting and forming.

### 3.1.2. Overview of Innovations in New Products

Steel products are constantly evolving, driven in part by research and development conducted in collaboration with steel-using industries. Indeed, most of the steel products used today did not exist just twenty years ago. Some examples of product innovations include:

- *High Strength Low Alloy Steels:* These steels are stronger than ordinary carbon steels, and are well suitable in applications that exert significant amounts of stress often at low temperatures. High-strength steels can be used to increase the fuel efficiency of cars by reducing the weight of its parts. These steels are also used in trucks, cranes, and bridges.
- *Improved Heat Resistance:* Steel products that are more heat resistant are suitable in the manufacture of machines that operate at high temperatures. By allowing thermal engines, for example, to operate at higher temperatures, these steels can result in improved energy efficiency. Moreover, since a given amount of steel used in these applications yields higher performance, the resource-savings are beneficial to the environment (Matsumiya, 2005).
- *Efficient Electrical Steels:* These steels can reduce the losses in electric motors and converters, and thus contribute towards energy savings (Matsumiya, 2005).
- *Corrosion-Resistant Steels:* Steel products have become increasingly resistant to corrosion, thanks to developments in coating. The industry strives to maintain steel's attractiveness as a material used in the automotive and other applications by developing steels that are resistant to wear, have long-lasting stability, and have tailored surface hardness. Corrosion-resistant steels

also extend the lifetime of the product. This reduces disposal requirements and, thus, improves the environmental impact of a given steel product.

### **3.2. Data on steel-related innovations**

#### **3.2.1. Patents: data and challenges**

This section of the paper focuses on a review of patents, as a proxy for innovative capacity and innovation activity. Patent data can be very useful for innovation analysis because they have the advantage of being very comparable across countries and time. However, it is subject to a number of measurement challenges due to the way the data are collected and organised. Examples are the home advantage, multiple inventors or patent quality issues that can result in erroneous interpretations. A brief overview of these challenges is provided in Box 2 below, but for a more detailed discussion, please refer to the OECD Patent Statistics Manual (OECD, 2009). It is important to keep these caveats in mind, particularly if any policy implications are to be drawn.

#### **Box 2. Challenges in analysing patent data**

##### ***Home advantage bias***

Patent indicators constructed on the basis of information from a single patent office are prone to the “home advantage” bias: in proportion to their inventive activity, domestic applicants tend to file more patents in their home country (or region) than non-resident applicants. Even though the Patent Cooperation Treaty (PCT), has helped mitigate these biases by ensuring a worldwide patent registration system, although problems of interpretation remain.

##### ***Multiple inventors from different countries***

As many inventions are increasingly carried out in joint collaboration, sometimes from entities located in different countries, there is potential for double counting (OECD 2009). In order to avoid double counting while ensuring that cross-border inventions are taken into account, “fractional patent counts” are normally used— i.e. each country will be assigned a fraction of the patent.

##### ***Patent quality***

An important caveat of using patent data *per se* is the lack of differentiation between more or less important patents. For example, the Bessemer patent and a patent to make an incremental change in the Bessemer patent will both count as one. Therefore, it would be important that patents are adjusted for their importance. OECD work on innovation statistics and patent analysis suggests a number of approaches, mostly based on patent citations (e.g. the number of times the patent appears cited in the future), that allow for weighing the patents based on their “quality” (see Squicciarini et al., 2013).

##### ***Strategic patenting and “patent trolls”***

Some companies may follow strategic patenting approaches. For example, companies may fill in patents to block access by competitors to a key technology, or inversely, to avoid being blocked by them. Some entities may even patent without any intention of bringing the invention to the market, but rather to obtain financial benefits from infractions of others using that technology (commonly known as “patent trolls”). On the other hand, companies may develop new processes and products and yet not patent them due to cost factors, secrecy reasons, confidentiality agreements, lead-time, complexity of design, the incorporation of specialist knowhow, the use of open source methods or other reasons and strategic approaches. As a result, patents may under or over represent the amount of innovation taking place and the net effect of these opposite sign biases is challenging to disentangle.

##### ***Coverage***

The development of patent systems and changing strategies for the protection of innovation through time means that an increase in the number of patents may not necessarily reflect more inventions/innovations, but rather an increase in the use of IPRs in general (and patents in specific) by companies.

It is also important to stress that patents represent only a specific component of innovation activity, thus should be complemented with other indicators such as R&D statistics, human capital and, when possible, indicators that allow distinctions to be made between product, process, organisational and other

types of innovation.<sup>22</sup> See OECD (2010a) for an overview of the different indicators that can be used to measure innovation.

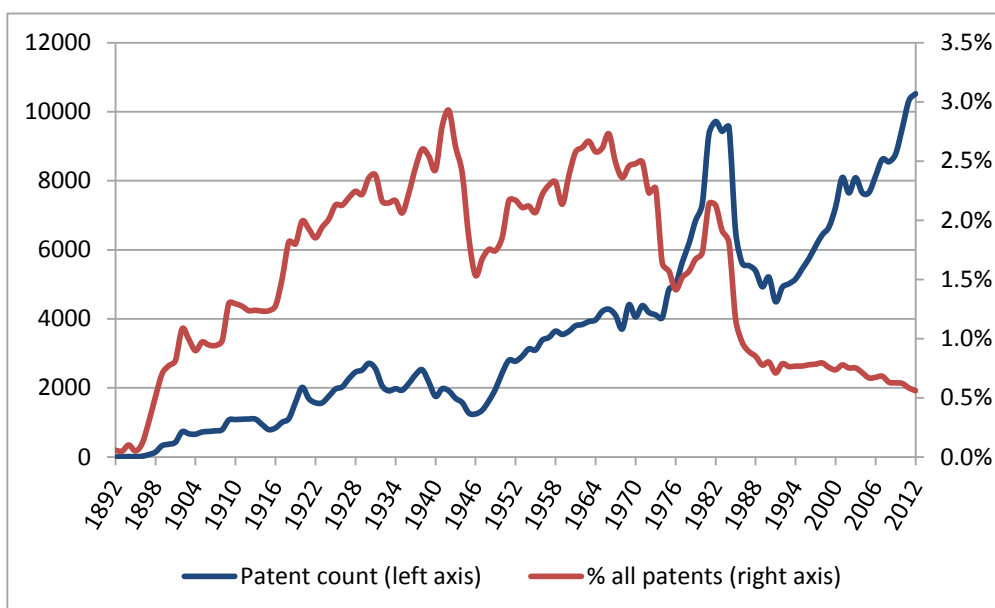
The patent data used in this paper were extracted from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT). Identifying steel-related patents is not straightforward since patents are classified according to technological fields rather than in terms of products or industries. The Annex describes the data source, the procedure used to identify steel-related patents, as well as the resulting steel patent dataset.<sup>23</sup>

### 3.2.2. Steel-related patents

Figure 11 below depicts the historical evolution of the number of steel patents since 1892, as well as their share of all the patents in each year. Three immediate observations from the patenting pattern are: *i*) the surge in steel patents during the late 1970s and early 1980s; *ii*) the increase in importance of steel-related technologies during the first half of the 20<sup>th</sup> century; and *iii*) the decline of steel patents relative to other technologies after the 1980s.

**Figure 11. Evolution of steel-related patents**

Historical, 1892-2012



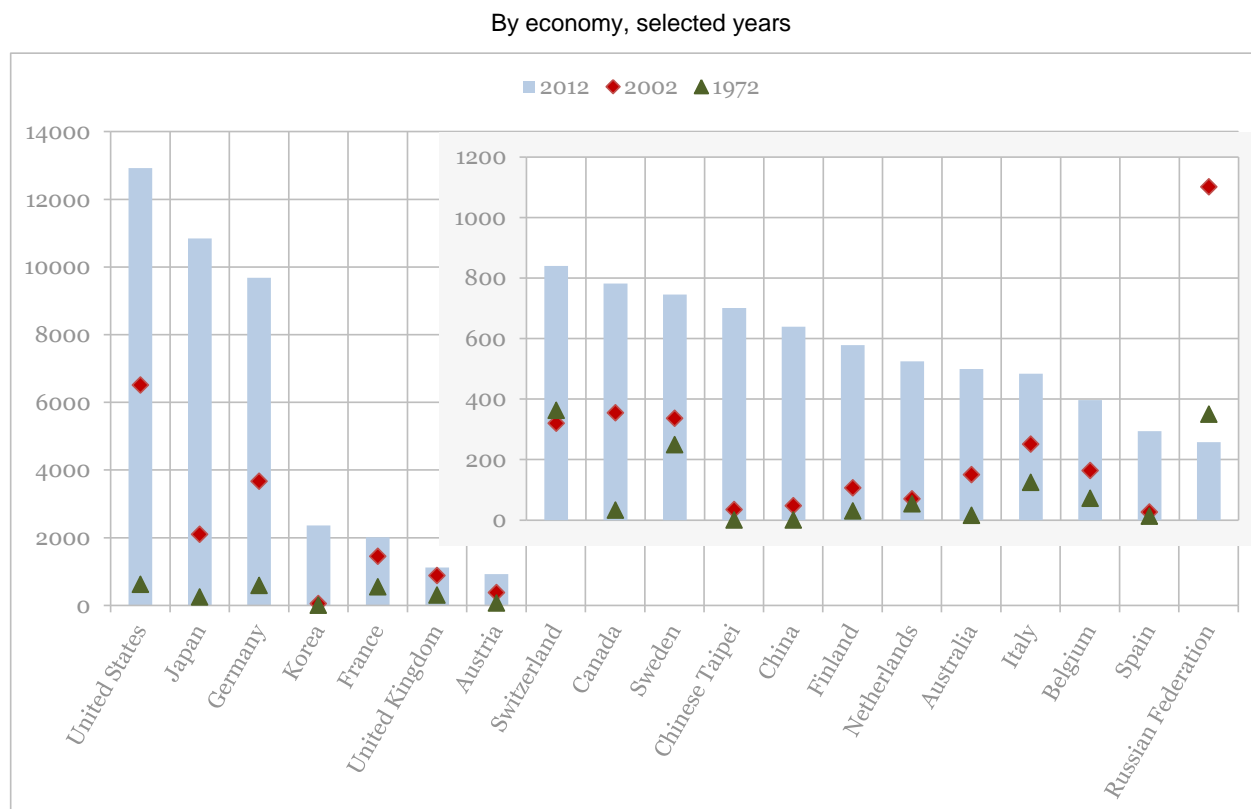
Note: Patent counts are the total number of steel-related patents in each year. The percentage of all patents is calculated as the ratio of steel-related patents to total patents in each year.

Source: OECD calculations based on data from PATSTAT.

Patenting activity in steel varies significantly across economies and over time. Figure 12 compares the patent stock by economy in 2012 against the same measure ten and forty years earlier. The patent stock indicates the accumulation of experience and knowledge over several years and decades, depreciated over time (see Annex for further details). The United States, Japan, and Germany accounted for the majority of patents during the 2000s, which is reflected in the patent stock in 2012. By 2012, United States' patent stock was more than five times that of Korea, the economy with the fourth largest steel patent stock right after Germany.<sup>24</sup> Naturally, there are significant differences over time. For example, while the patent stock in the United States or Japan increased substantially over the last four decades, Russia experienced a

decrease in the patent stock, notably during the years 2000, as it exhibited a very limited number of patents and the weight of older patents was reduced over time because of depreciation.

**Figure 12. Steel patent stock by economy**

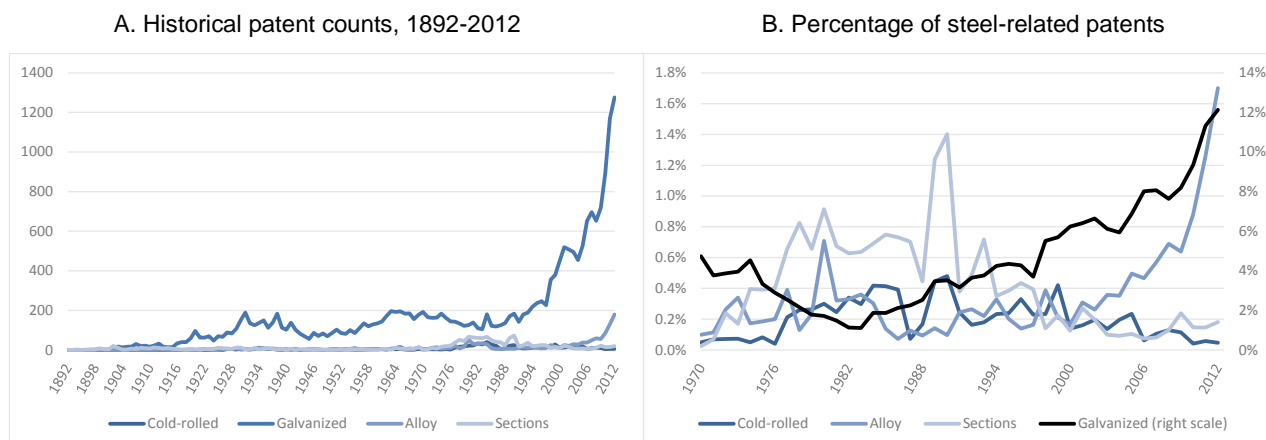


Note: Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. See the Annex for further details.

Source: OECD calculations based on data from PATSTAT.

### Innovations in steel products and along steel production stages

Patent data also allow disentangling the extent of innovation activity within certain products or production processes. Figure 13 below shows the recent evolution in patenting activity related to four selected types of products, namely, sections, cold-rolled (long and flat steel), galvanised and alloy steel.<sup>25</sup> Patenting activity has been historically higher in galvanised steel (a high-value added product), both in absolute (Panel A) and relative terms (Panel B). However, it is interesting to note that during the 1970s and early 1980s, the rate of inventions in galvanised steel decreased, in contrast with the increase in patents related to other products, namely the lower value-added sections. The most significant relative increase in patenting activity in recent years has occurred in alloy steel (Panel B) that is usually regarded as a higher value-added product. These results should nevertheless be regarded with some caution because comparing patent levels across narrowly defined fields can be problematic.

**Figure 13. Patent activity in selected steel products**

*Note:* Patent counts are the total number of steel-related patents in each year. Technologies pertaining to other steel-related products are not included. Please refer to the Annex for details on the patent codes used.

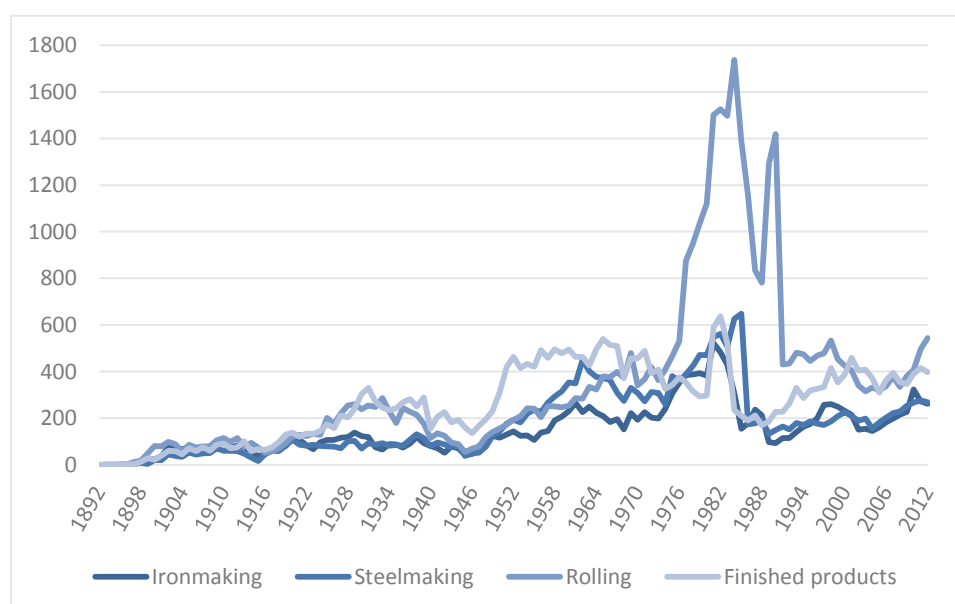
*Source:* OECD calculations based on data from PATSTAT.

Innovating in higher value-added steel products can accrue greater benefits. Anecdotal evidence suggests that exporters of higher value-added steel products performed better than exporters of commodity steel products during the financial crisis of 2008-2009. In this context, new findings suggest a positive correlation between innovation activity and export specialisation in higher value-added steel segments (de Carvalho and Sekiguchi, 2015). In addition, exporters of high value-added steel were more insulated from the global demand downturn in the aftermath of the financial crisis; exports from Japan, for example, which specialises in sophisticated and high quality steel products, declined less relative to many other countries.

Patent activity is also different along the steel production process, with more innovations taking place at different stages of production. Figure 14 depicts the evolution of innovation activity (proxied by patents) in steelmaking processes and compares it to iron making, as well as downstream processes such as rolling and production of finished products.<sup>26</sup> Even though patenting activity in these fields is naturally highly correlated and sometimes overlapping (i.e. the same patent may apply to both rolling and steelmaking), it is nevertheless interesting to note that patenting activity is (and has been) higher in downstream activities.

**Figure 14. Patent activity along the steel production process**

Historical patent counts, 1892-2012



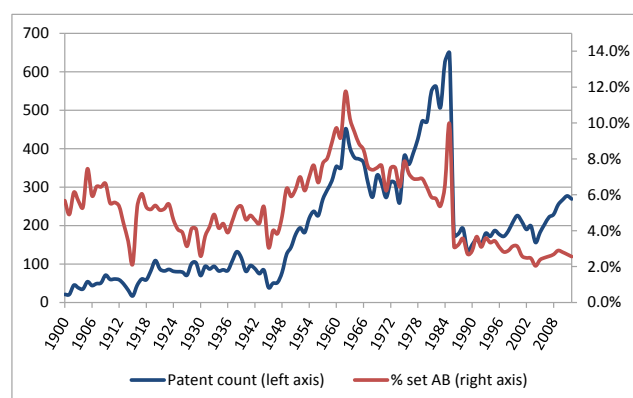
Note: Patent counts are the total number of steel-related patents in each year. A patent may apply to several production stages. In addition, technologies pertaining to other steel-related processes or products are not included. Therefore the sum of all the patents in this chart does not necessarily reflect the universe of steel-related patents. Please refer to the Annex for details on the patent codes used.

Source: OECD calculations based on data from PATSTAT.

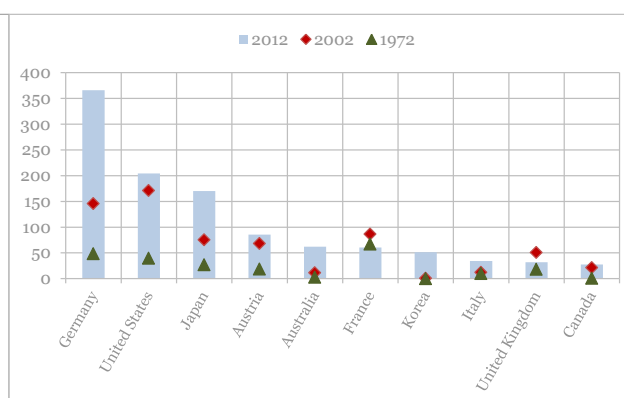
Figure 15 focuses on the historical evolution of inventions specifically in steelmaking processes (i.e., not in ironmaking, rolling or finished products as shown above) and recent patent stocks by economy. Interestingly, the share of steelmaking innovations has been relatively low over the past 20 years (Panel A). Leading economies in patenting activity related to steelmaking processes included Germany, the United States and Japan in 2012 (Panel B).

**Figure 15. Steelmaking inventions**

A. Historical patent counts, 1890-2012



B. Steel patent stock by economy, selected years



Note: Patent counts are the total number of steel-related patents in each year. A patent may apply to several production stages. In addition, technologies pertaining to other steel-related processes or products are not included. Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. Please refer to the Annex for details on the patent codes used.

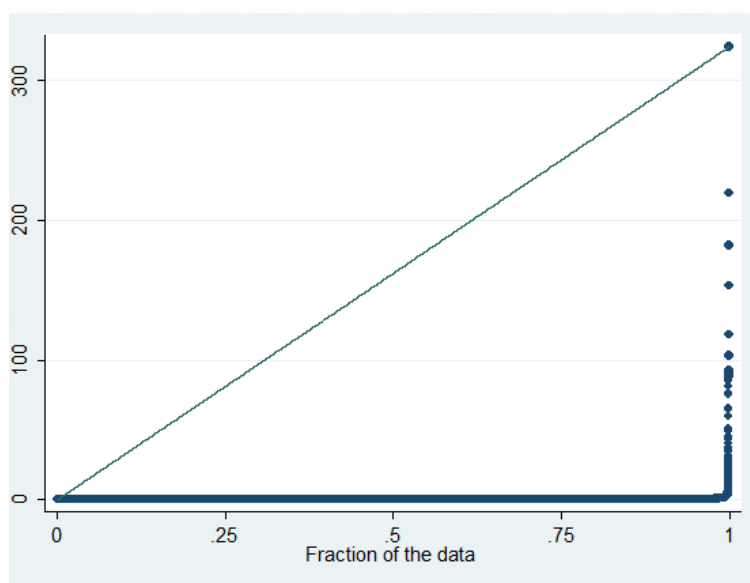
Source: OECD calculations based on data from PATSTAT.

### 3.2.3. Steel-related patents by steelmaking companies

The analysis in this paper has thus far focused on steel-related innovations. These are however not necessarily the same as innovations carried out by the steel industry itself, because some entities (other than steelmaking companies) also patent inventions in steel-related technologies — e.g. companies in upstream or downstream industries, business services firms or research institutes.<sup>27</sup> Identifying innovation activity by steelmaking companies using patents can therefore be rather challenging. In addition, different patents by the same company (assignee) can be registered with slightly different names, which make any statistical analysis very resource intensive as it requires matching company names.<sup>28</sup> Moreover, companies do not fill patents every year so, for presentation purposes, the patent analysis in this section always refers to the patent stock of each company in 2012. A detailed description of the strategy used to identify top patenting steelmaking companies is provided in the Annex.

As expected, many inventions and innovations in steel are carried out by non-steelmaking companies. Moreover, patenting activity is highly concentrated in a very small number of entities — Figure 16 is remarkably clear with this respect. Even though 90% of the top 100 patent applicants in the field are not steelmaking companies, steelmakers account for about 32% of the total patent stock pertaining to the top 100 list. In addition, some steelmaking companies feature prominently high in the list of 100. Table 2.A shows that four steelmaking companies feature amongst the top 10 entities with the highest patent stock in steel-related technologies in 2012.

**Figure 16. Distribution of patent applicants in steel-related technologies**



Notes: The chart plots the patenting distribution using a quantile plot. In the horizontal axis, companies are ranked according to their patent stock in 2012, which is given by the vertical axis. The patent stock is calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. See the Annex for further details.

Source: OECD calculations based on data from PATSTAT.

Table 2.B lists 10 steelmaking companies, identified amongst the 100 top entities with the highest patent stock in steel-related technologies in 2012. Within the top 100 list, JFE Steel had the highest score in this technological field, followed by Nippon Steel in second, Kobe Steel in 5<sup>th</sup> place and POSCO in 8<sup>th</sup> place (Table 1.A). These companies are ranked first, second and third in the steelmaker-specific list (Table 2.B). For reference, the entity in the 100<sup>th</sup> position had a patent score of 13.0. Other top 100 entities in steel-related technologies include for example steelmaking equipment providers such as Siemens (score

of 118.1) or SMS Siemag (132.2), downstream using automotive (e.g. Daimler, 65.1) or shipbuilding (e.g. Mitsubishi Heavy Industries, 28.0) industries, or even business service providers (e.g. Outotec, 35.0).

Top patenting steelmaking companies are likely to have dedicated research centres, as is known to be the case for the majority of the companies listed in Table 2.B. Inventions and innovations are much more challenging to achieve without equipped laboratories and highly skilled scientists and researchers. Some of the companies may also have dedicated patent personnel, to ensure that the benefits of inventions remain accrued by the company, at least for a given number of years. As mentioned in Section 2.2, collaboration with higher education institutions and public research institutes is very important. It is interesting to note that a number of research institutes appear in the top 100 list of steel patent assignees. Examples include the Fraunhofer Institute (score of 20.8) or the Korea Institute of Industrial Technology (15.9).

Further work on improving firm-level patent data available for the steel sector would certainly help shed some light on which firms are more innovative, why they are so and what the implications are for steelmaking companies' economic performance. Such analysis would help identify key policy levers and improve the design of innovation policy instruments to foster innovation in the steel sector.

**Table 2. Top patent applicants in steel-related technologies**

A. Top 10 patent applicants: All

Rank	Name	Patent stock 2012
1	JFE Steel	324.4
2	Nippon Steel & Sumitomo Metal	267.5
3	Tokyo Electron	182.3
4	Applied Materials	153.4
5	Kobe Steel	144.3
6	Siemens	118.1
7	SMS Siemag	107.3
8	Posco	103.1
9	JX Nippon Mining Metals	93.2
10	Samsung Display	88.4

B. Top 10 patent applicants: Steelmaking companies

Rank	Name	Patent stock 2012
1	JFE Steel	324.4
2	Nippon Steel & Sumitomo Metal	267.5
3	Kobe Steel	144.3
4	POSCO	103.1
5	Baoshan Iron Steel	50.4
6	Thyssenkrupp Steel	42.0
7	Nisshin Steel	18.5
8	Sanyo Special Steel	16.2
9	Tata Steel	15.3
10	Voestalpine Stahl	15.1

Note: Score is the patent stock, calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. Location is not provided because companies may file patents in different patent offices across the world, notably in the case of multinationals. See the Annex for further details.

Source: OECD calculations based on data from PATSTAT.

### 3.3. Greening Steel: Innovation for Climate Change Mitigation in the Steel Sector

The world steel industry is an important CO<sub>2</sub> emitter<sup>29</sup> and is therefore being called on to play a major role in mitigating climate change, not only by reducing the CO<sub>2</sub> emissions of its production processes<sup>30</sup> but also by contributing to the infrastructure of a low-carbon economy. In the long run, significantly reducing the industry's emissions will require a shift away from current production methods towards new methods of production. The industrial application of already existing technologies could contribute significantly to mitigating climate change. As an example, wider diffusion of the use of more energy-efficient production practices could significantly reduce CO<sub>2</sub> emissions. In the longer term breakthrough technologies will be required to reduce the impacts still further. In particular, the adoption of Carbon Capture and Storage technologies would reduce CO<sub>2</sub> emissions from the sector drastically. Public policy has an important role

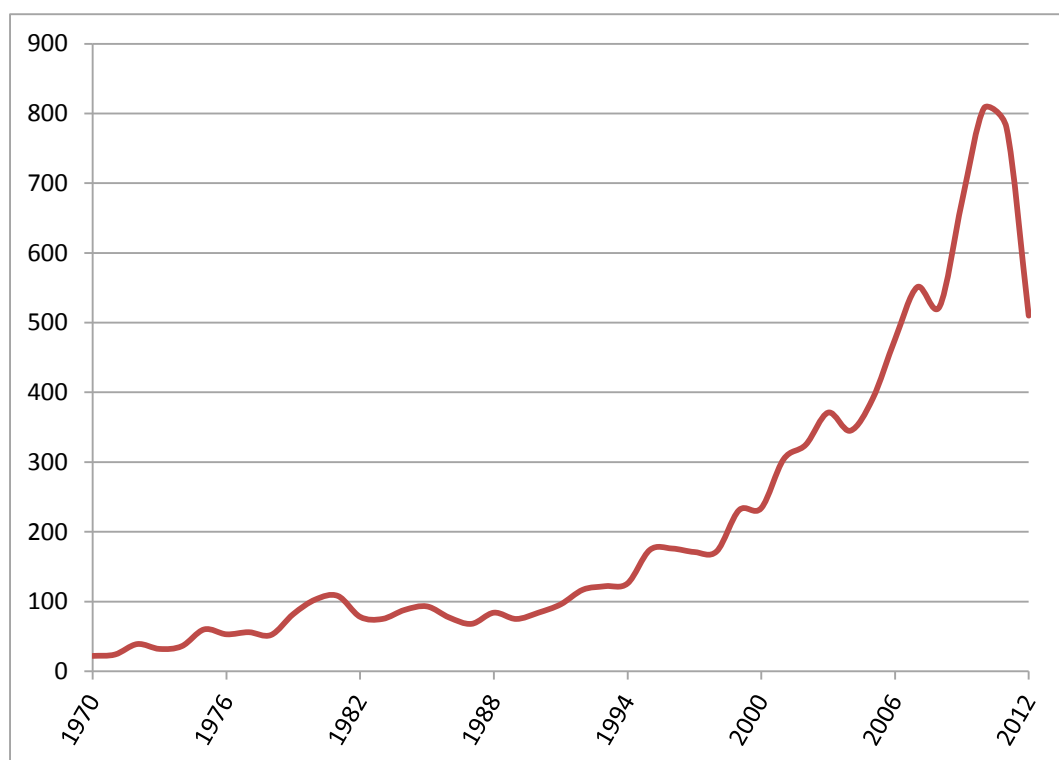
to play in encouraging such developments (OECD, 2011, 2012c).<sup>31</sup> A better understanding of how to incentivise and induce both incremental and radical innovations in steel that can help mitigate climate change is needed.

### *3.3.1. Innovations for green(er) steel*

While the steel industry has often been subject to critique for its environmental performance, it has nevertheless been making efforts to innovate and to improve its environmental performance. For example, World Steel Association members have agreed on a common framework to work towards reducing their carbon footprint. This includes: i) the development and application of new steels to improve the energy efficiency of steel-using products in society; ii) expenditure on research and development to identify breakthrough steelmaking technologies with the potential of reducing steel's CO<sub>2</sub> emissions significantly; iii) improving plant performance through benchmarking and technology transfer; and iv) a common measurement and reporting system for steel plant CO<sub>2</sub> emissions (World Steel Association, 2013).

These efforts are reflected in patent data. Due to the fine-grained nature of patent classification systems, such data can provide some insights into technologies that have climate change mitigation potential. The system for tagging low carbon-related patents developed by the European Patent Office (see Veefkind et al., 2012 and EPO, 2013 for details) has allowed for the identification of inventions that may contribute to mitigating climate change (see Haščič, I. and M. Migotto 2015 for indicators of environment-related innovation). Recent work at the OECD analyses the trends in climate change mitigation technologies and how policy can contribute to the acceleration and diffusion of innovations in this field (see OECD 2012c).

The rate of innovation in carbon mitigation related technologies in steel has been increasing over the last decades. Figure 17 depicts the evolution of the number of patents that relate climate change mitigation in the steel sector.<sup>32</sup> It is interesting to observe that, from 1970 until around the financial crisis of 2008, the number of low-carbon patents in steel technologies increased very rapidly.

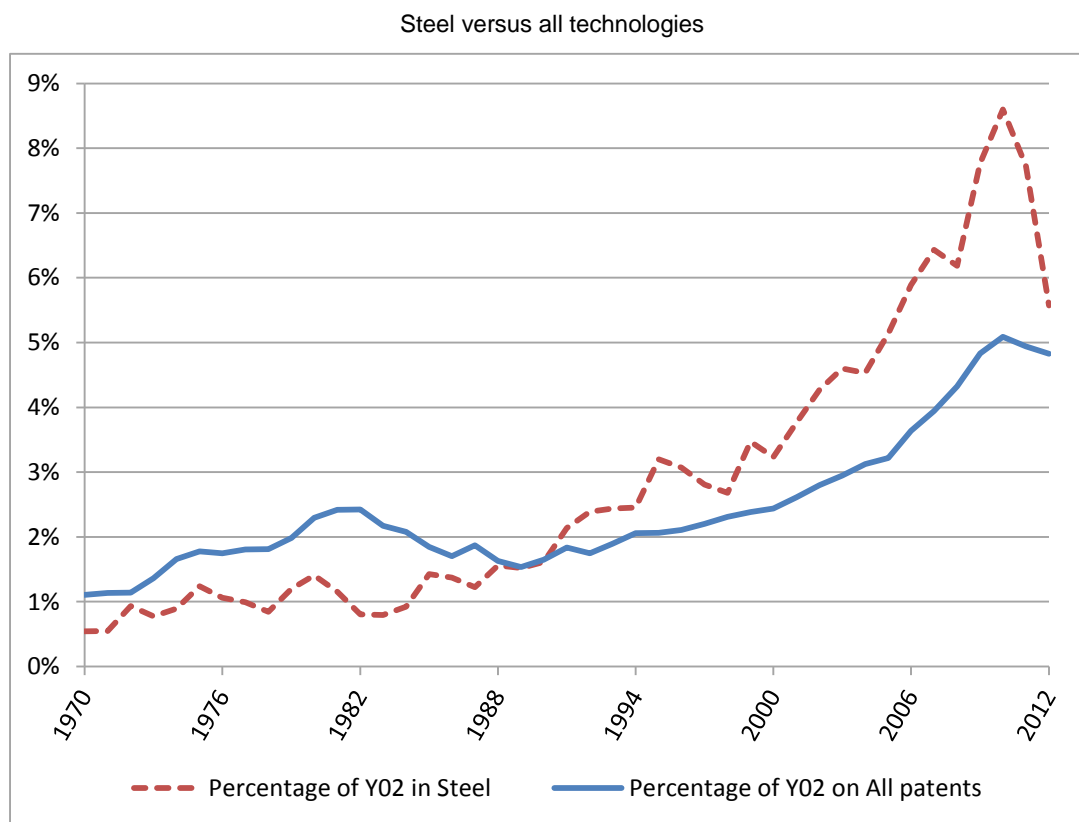
**Figure 17. Carbon mitigation related patents in steel**

*Note:* Environmentally related patents are obtained through the Cooperative Patent Classification system tag Y02 "Technologies or applications for mitigation or adaptation against climate change". Steel patents related to the environment result from the intersection of steel-related patents and Y02, as described in the Annex.

*Source:* OECD calculations based on data from PATSTAT.

The rate of increase was about the same rate as the total number of low-carbon patents in all fields combined. However, given that the rate of increase of patent counts overall in the sector is lower than the rate of patenting in the economy overall, the share of carbon mitigation related patents in steel has increased at a faster rate than the share of low-carbon innovations in general. This suggests that the "direction" of innovation in steel related technologies is gradually moving towards climate change mitigation, to a greater extent than elsewhere.

The count of patents related to climate change mitigation in all fields should nevertheless be regarded with some caution. Some economic activities may feature minor emission and environmental impacts but yet spawn large inventive activity. Therefore, as efforts to mitigate climate change become more concerted, it would be expected that the rate of climate mitigation innovation in the steel sector would increase relative to the economy as a whole. It is therefore not surprising that low-carbon innovation has become relatively more prominent in the steel sector when compared to patented climate change mitigation inventions in general since the late 1980s. Moreover, as can be seen in Figure 18 the share of carbon mitigation related patenting activity in steel has been decelerating in recent years, at a higher rate than overall climate change mitigation in all combined fields.

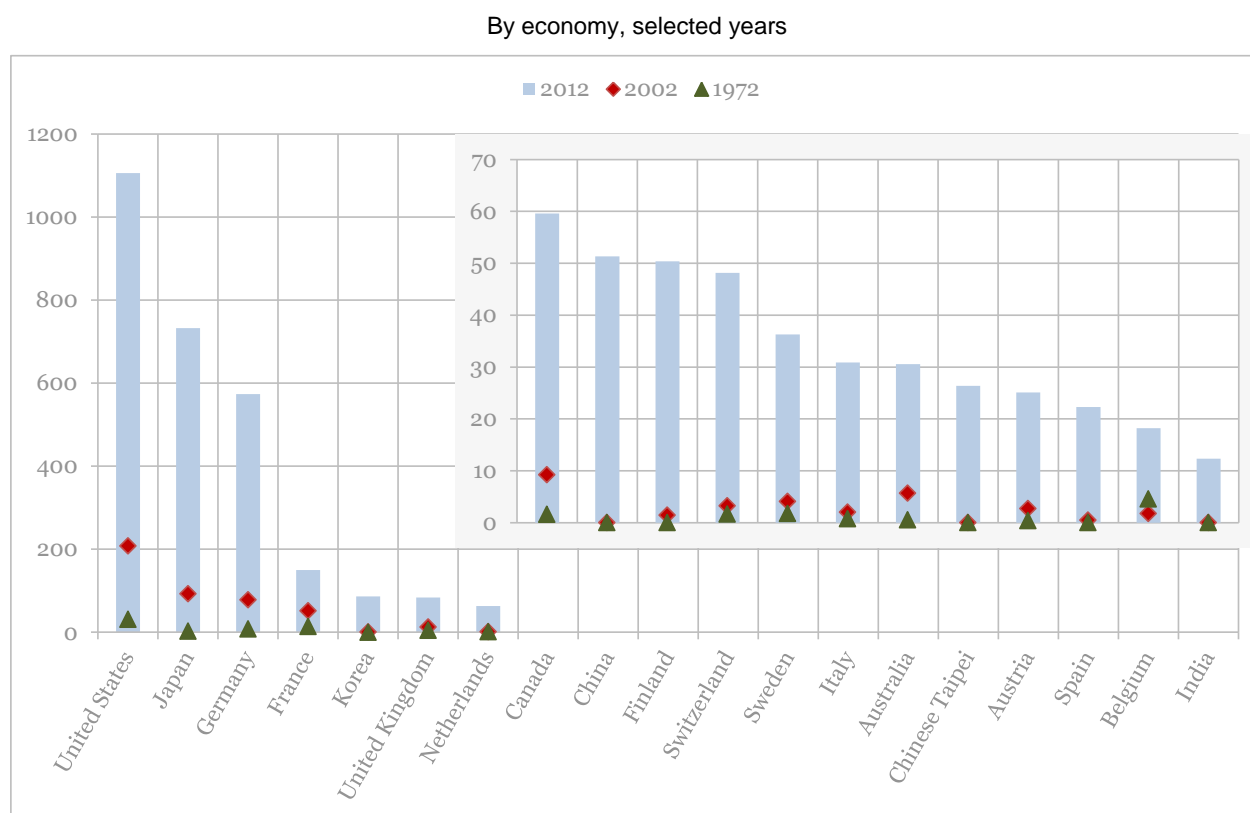
**Figure 18. Low carbon related patents as a percentage of total**

*Note:* Low carbon related patents are obtained through tag Y02. Steel patents related to climate change mitigation result from the intersection of steel-related patents and Y02, as described in the Annex.

*Source:* OECD calculations based on data from PATSTAT.

Patenting activity is very different across economies. Figure 19 shows the carbon mitigation, steel related patents across selected economies. The United States boasted the highest carbon mitigation patent stock in 2012 as well as in 2002 and 1972. A large number of carbon mitigation patents related to steel production were also patented by Japan and Germany during the last ten years, resulting in a very high stock of steel-related carbon mitigation technologies in these economies.

It is important to note that innovations relevant to mitigation in the steel sector come from a wide variety of actors. Indeed, steelmaking companies do not appear to be predominant as the owners of patents for steel-related carbon mitigation technologies. Out of the top 100 entities with the highest patent stock in this field in 2012, only two steelmaking companies were identified – Thyssenkrupp with a total stock of 4.3 and JFE Steel with a patent stock equal to 4.1.<sup>33</sup> By and large, patenting activity in steel-related carbon mitigation seems to be carried out mostly by companies in upstream mining companies (Sumitomo Metal Mining with a patent stock of 4.8) or downstream automotive companies (Nissan Motor with a patent stock of 2.5), business services companies that focus on providing services and technologies for steel companies (e.g. Outotec, 4.2), or even public research institutes (e.g. Korea Institute of Industrial Technology, 4.0) and universities (e.g. Massachusetts Institute of Technology, 2.0).<sup>34</sup> However, it should be noted that innovative research projects resulting in patented inventions may be carried out in collaboration with or commissioned by steelmaking companies.

**Figure 19. Stock of steel patents categorised as low carbon**

Note: Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. Steel patents related to climate change mitigation are those resulting from the intersection of sets AB and Y02, as described in the Annex.

Source: OECD calculations based on data from PATSTAT.

### 3.3.2. Capture and storage of greenhouse gases

The industrial application of already existing technologies could contribute to mitigate climate change. As an example, increasing the dissemination and application of Carbon Capture and Storage (CCS) technologies could, in the future, significantly reduce CO<sub>2</sub> emissions. The integration of CCS in iron and steel making processes is currently recognised as the only available way to enable the deeper carbon emissions reductions levels required to stabilise emissions.<sup>35</sup> Box 3 provides a brief overview of CCS. Further detail is available in the latest edition of the *Energy Technology Perspectives* published by the International Energy Agency (IEA, 2015).

Within the system for tagging low carbon-related patents developed by the EPO, a specific sub-tag has been created to identify technologies that relate to the capture and storage of greenhouse gases. Recent work at the OECD suggests that the rate of invention has accelerated in CCS (OECD 2012c). While the low number of observations in such a narrow technological field renders the analysis of CCS technologies (a sub-category of greenhouse gas mitigation technologies) rather challenging for steel, it is nevertheless remarkable that tagging can be made at such a granular level.<sup>36</sup>

While the technologies required for the separation of carbon date from the early 1900s, these were not developed with a view towards carbon capture and storage but for other purposes. It is not until the 1990s that inventive activity in these areas starts to pick up, reflecting the increased recognition of the potential value of such technologies in climate change mitigation. Nonetheless, the number of steel-related patents

associated with these technologies remains very limited. Nevertheless, Figure 20 below shows the evolution of patenting activity in this area and compares steel-related patents to the total number of inventions associated with capture and storage of greenhouse gases.

### Box 3. Carbon Capture and Storage

Carbon capture and storage, or CCS, prevents CO<sub>2</sub> from fossil fuel combustion from accumulating in the atmosphere. In CCS, CO<sub>2</sub> can be captured from large emissions sources or, potentially, directly from the air. It can be stored deep underground or even bound in minerals. The most common example of CCS today involves capture of CO<sub>2</sub> from fossil fuel use, followed by CO<sub>2</sub> transport via pipeline and its permanent storage in geological formations, such as deep saline aquifers or depleted oil and gas fields. CCS is expected to play a unique and vital role in the global transition to a sustainable low-carbon economy, in both power generation and industry.

The reduction of iron ore is the largest energy-intensive step for the production of primary steel. There is limited energy savings potential when comparing current state-of-the-art blast furnaces (12 GJ/t crude steel or 1.2 t direct CO<sub>2</sub>/t crude steel) to practical minimum energy requirements (10.4 GJ/t crude steel or 1.1 t direct CO<sub>2</sub>/t crude steel). In this context, the integration of CCS in iron and steel making processes is recognised as the only available way to enable the deeper carbon emissions reductions levels required.

The component technologies for CCS are well-understood and many have been used commercially for decades. For example, the Sleipner oil and gas project in Norway has had almost 20 years of successful CCS operations. There are now 15 large-scale CCS projects operating globally across a range of applications, with a further 7 projects expected to come online in the next 2 years. These include the Emirates Steel Industries project that will capture 0.8 million tonnes of CO<sub>2</sub> per year from a direct reduced iron (DRI) steel plant when it begins operation in 2016. The CO<sub>2</sub> will be supplied to Abu Dhabi National Oil Company (ADNOC) for use in CO<sub>2</sub> enhanced oil recovery and its permanent retention in the oilfield will be monitored.

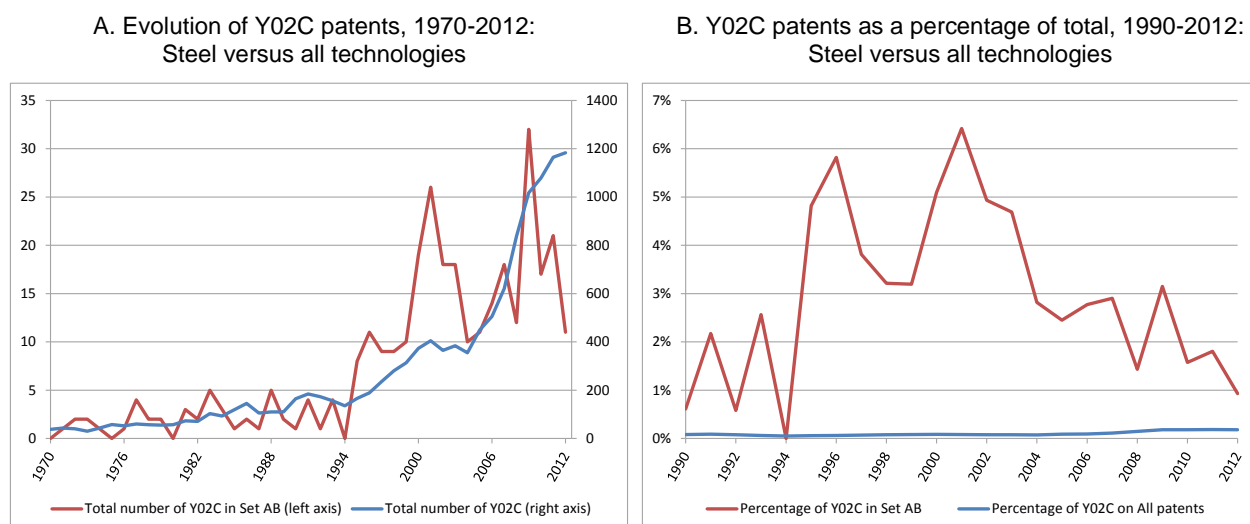
However, for some applications, such as capturing the CO<sub>2</sub> from integrated steel mills or cement plants for climate change mitigation, the technologies have only been put together at a very limited number of installations. For iron and steel production, several options for deep emissions cuts integrating CCS are being explored. These include:

- An **upgraded smelting reduction (SR)** technology combining a hot cyclone and a bath smelter avoids the use of coke or sinter, and maximises the CO<sub>2</sub> content of the off-gases through pure oxygen operation, making CO<sub>2</sub> capture more straightforward. A 90-day pilot plant trial is planned for 2016.
- **Oxy blast furnace and top gas recycle:** The CO<sub>2</sub> content of the top gas is raised by replacing the air in the blast furnace with oxygen. The top gas is recycled back to the BF as reducing agent, after partially capturing the CO<sub>2</sub> contained, which decreases coke requirements.
- **Coke oven gas (COG) reforming:** Increasing the hydrogen concentration of COG through reforming tar contained in the gas provides an effective reducing agent to reduce iron ore in BF and SR processes with a direct benefit on net energy consumption. The integration of this technology in oxy blast furnaces maximises the emissions reduction benefit and enables an easier implementation of carbon capture.
- An **upgraded DRI process** that reuses off-gases from the shaft as reducing stream after CO<sub>2</sub> capturing. This process also avoids the need for coke or sinter.
- **CO<sub>2</sub> capture applied to on-site utilities and general combustion equipment.** Addition of a post-combustion CO<sub>2</sub> capture unit to one or more of: hot stoves, steam generation plant, coke oven batteries and lime kiln.

Source: For more information, see Chapter 5 and Chapter 6 of IEA (2015) and IEA's website, available at: <http://www.iea.org/topics/ccs/>.

Inventions in steel-related technologies featuring elements of capture and storage of greenhouse gases (Y02C) were intermittent before the mid-1990s, with only a handful of new patents filed every year, if at all. During the late 1990s, patenting activity in steel related Y02C rapidly increased, in line with the increase in Y02C inventions in all technology fields (Panel A of Figure 20). Interestingly, the importance of Y02C in steel-related technologies was quite significant during the late 1990s and early 2000s, but has been decreasing ever since (Panel B). This contrasts with the steady growth in importance of technologies for capture and storage of greenhouse gases in general.

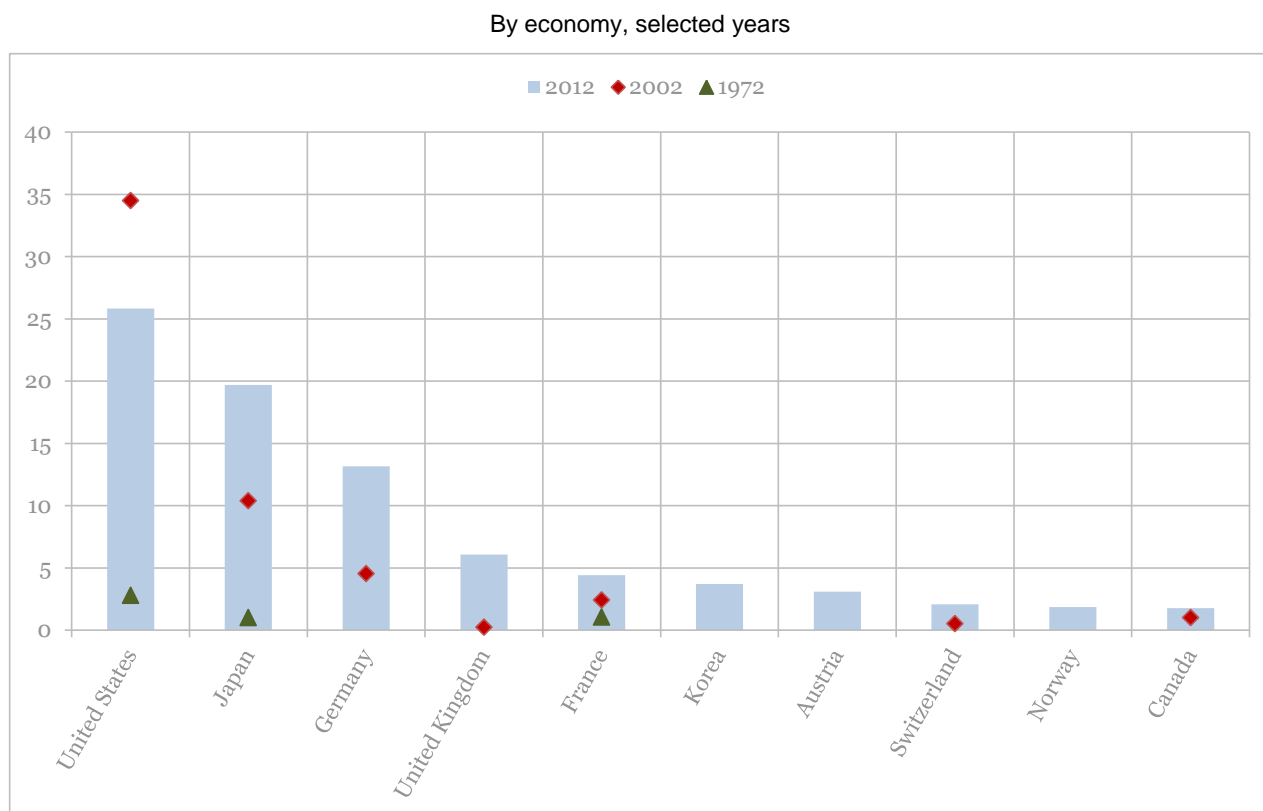
**Figure 20. Capture and storage of greenhouse gases**



*Note:* Patents on capture and storage of greenhouse gases are obtained through the CPC tag Y02C “Capture, storage, sequestration or disposal of greenhouse gases (GHG)”. Steel patents related to capture and storage of greenhouse gases are those resulting from the intersection of sets AB and Y02C, as described in the Annex.

*Source:* OECD calculations based on data from PATSTAT.

Geographically, inventions of capture and storage of greenhouse gases in steel-related technologies have been more prominent in economies such as the United States, Japan or Germany (Figure 21 below). It is interesting to note that patented inventive activity increased in Germany and Japan between 2002 and 2012, but fell in the United States, although the United States remains the most important patenting country in this field.

**Figure 21. Stock of steel patents related to the capture and storage of greenhouse**

Note: Patent stock is calculated as the cumulative sum of patent counts over time, depreciated at an annual rate of 15%. Steel patents related to the capture and storage of greenhouse gases are those resulting from the intersection of sets AB and Y02C, as described in the Annex.

Source: OECD calculations based on data from PATSTAT.

Amongst the top 100 patenting entities, steelmaking equipment providers feature prominently with Siemens exhibiting the highest patent stock in 2012 (1.44) and Danieli highly ranked with 0.51. With regard to steelmaking companies, JFE Steel with a score of 1.04 is ranked first amongst steelmaking companies and third within the broad top 100 list. Hyundai Steel scores 0.01 and Nippon Steel also appears in the top 100 list with a score of 0.003 (the same as the 100th observation).

Deep reductions of emissions from integrated steel mills is a high cost climate mitigation step, but may nevertheless prove to be an important means of achieving significant overall emissions reductions. This means that, while CCS deployment may not be an immediate requirement for steelmaking, development of better technologies that can enable its wider adoption in the coming decades is more urgent. Because steel is a globally traded commodity, the level of carbon pricing that would make CCS economically attractive are politically and economically difficult to implement. While pricing is essential, the importance of targeted government support and research efforts for innovative projects in this area would be a necessary complement, driving down the costs of adoption over time. Recent work at the IEA provides an overview of the challenges with CCS deployment, as well as policy instruments that can be used to incentivise CCS in industrial applications (IEA, 2014 and Bennett and Heidug, 2014).

### *3.3.3. Policy could foster progress and dissemination of environmentally friendly technologies in steel*

It has long been argued that a breakthrough steelmaking technology that can radically reduce CO<sub>2</sub> emissions is needed. The steel industry is making efforts to fund research into breakthrough low-carbon technologies and a number of R&D programmes have been put in place for this purpose (see OECD, 2010b and the World Steel Association, 2013 for an overview). There has been an increase in patented inventions since the 1980s, both in absolute terms as well as relative to environmentally related patents overall, but the latest available data show that patented inventions related to climate change mitigation are relatively more prominent in the steel sector when compared to patented low-carbon technologies in general since the late 1980s, as would be expected given the importance of the sector to climate mitigation efforts.

Data suggest that the direction of invention in steel-related technologies is turning towards climate change mitigation. However, a recent downward trend could be of concern given the environmental challenges ahead. Nevertheless, the key question is not so much about the number of inventions, but rather about their quality and the extent to which they are implemented and disseminated – only then is it possible to reap the economic and environmental benefits.

Technological change is essential to address environmental challenges and policy has an important role to play with this respect (OECD, 2011, 2012c). A better understanding about how to incentivise and induce both incremental and radical innovations in steel that can help mitigate climate change is needed. In addition, the right incentives and framework conditions need to be in place to make sure that technologies that address pressing environmental challenges are diffused and adopted across the industry. This will require the use of both market-based measures, as well as targeted technology support policies. Further increasing energy efficiency, supporting research into carbon capture and storage, reusing industrial wastes and diversifying product applications are important goals for the steel industry. Economic uncertainty and policy unpredictability, and the need to manage risk and maintain competitive advantage, can create substantial challenges to technological progress. International collaboration and industry-government cooperation will be needed to further improve the energy and environmental performance of the steel sector.

## **4. Productivity in the steelmaking industry**

Productivity, in its broadest interpretation, is meant to capture the efficiency by which inputs are turned into outputs (Hulten, 2001; OECD, 2001). Recent OECD work on measuring effective capacity has noted the importance of further understanding how efficiently capacity is used (OECD, 2014a). The way that machines and equipment are utilised, labour shifts organised, production processes designed, and how companies learn about how to best use resources (among other drivers of productivity) can have a substantial effect upon how much output can be obtained using the same machinery in place (nominal capacity).

A recent case study of a steel plant by Hendel and Spiegel (2014) shows that the plant studied was able to double its production over a 12-year time span, even though its capital stock (nominal capacity) and labour force remained constant. A significant share of this increase remained unexplained after controlling for a number of factors, suggesting that learning and “tweaking the production process” played a major role.<sup>37</sup> This unexplained effect that results from combining inputs in a more efficient way is defined here as multi factor productivity.

Labour productivity data are widely used to analyse productivity, mostly due to their availability.<sup>38</sup> However, this measure does not control for capital intensity. Stronger growth in labour productivity could for example result from capital deepening. This distinction is particularly important to take into account

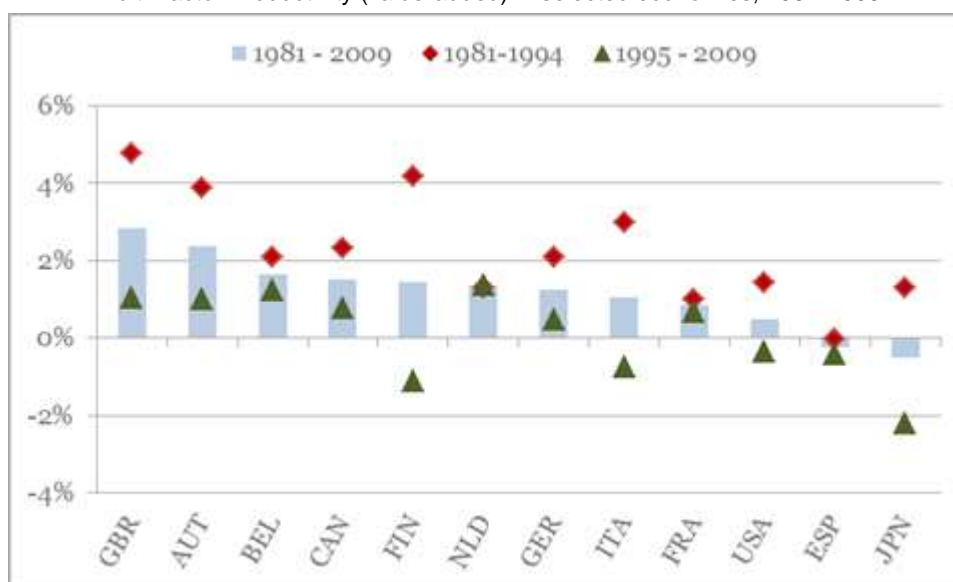
when analysing the steel sector. For example, BOF technologies are more capital intensive than EAF technologies (D’Costa, 2003). Therefore, an exercise comparing labour productivity estimates would be flawed — companies (or economies) where BOF is the prevailing technology would exhibit higher labour productivity figures, without necessarily meaning that they were more efficient.

Multi- factor productivity (henceforth productivity) that takes into account not only labour inputs but also capital and intermediate inputs is a much more polished concept that can be used to account for efficiency gains.<sup>39</sup> The idea is that, once all inputs are taken into account, the remaining output (or value-added) growth results from how well the different inputs are combined and how efficiently they are used.

#### 4.1. Aggregate productivity in the steel industry

Over the last three decades, productivity in the basic metals and fabricated metals industries has increased substantially in a number OECD economies.<sup>40</sup> Figure 22 below compares the average annual productivity growth rate between 1981 and 2009 amongst a selected number of economies where data are available, and at a level of aggregation that includes both ferrous and non-ferrous metals sectors. Data on productivity levels is very limited and therefore not included here. Different factors can contribute to higher productivity growth. Examples are investments in new machinery and equipment that embody new technologies that allow workers to perform the same tasks within a shorter time frame or investments in knowledge-based assets such as R&D, ICT and human capital (OECD, 2013b). In addition, the introduction of new technologies can lead to increased competition amongst producers with older technologies, resulting in a reallocation of production and higher productivity in the aggregate (see Collard-Wexler and De Loecker, 2013 for the minimill example from the U.S.).

**Figure 22. Average annual productivity growth rates in basic metals industries**  
Multi Factor Productivity (value-added) in selected economies, 1981-2009



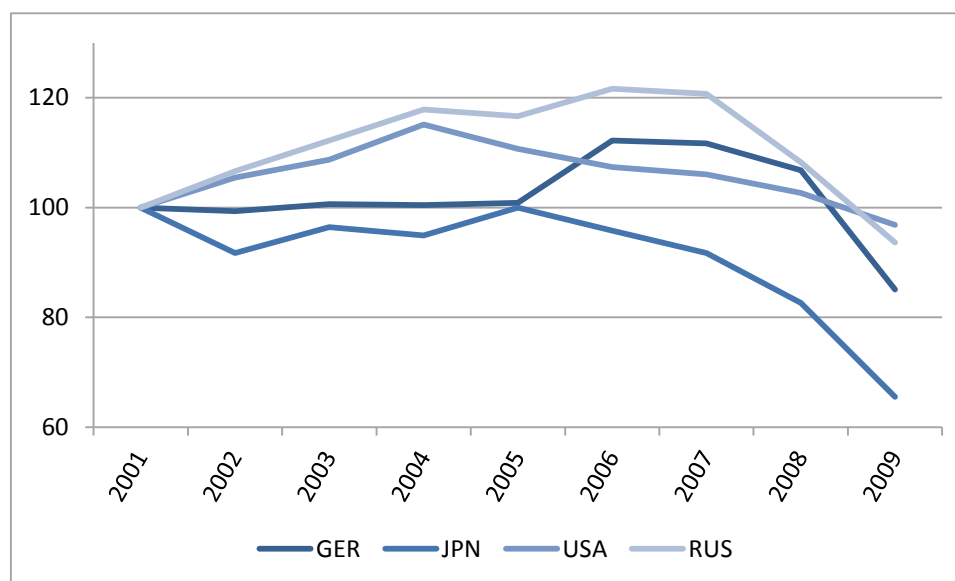
*Note:* Long-term comparable data on MFP growth during the period 1981-2009 are only available for the selected economies. Data for more recent years (namely after 2009) are only available for Belgium, Finland, Sweden, USA and Canada and shows positive average growth rates. Industry is defined as an aggregate of basic metals (ISIC 4 industry code 24) and fabricated metal products (ISIC 4 industry code 25) due to data availability. The underlying data as well as explanatory documents can be found at the EUKLEMS project webpage: <http://www.euklems.net/>. Due to data availability, data are presented as changes and not levels, meaning that the analysis is not made based on productivity, but rather on how much productivity has changed.

*Source:* OECD based on EUKLEMS data, available at: <http://www.euklems.net/>.

Productivity growth during the period 1981-1994 in the basic metal industries was considerable, for example reaching an average annual rate of 4.7% in the U.K., 4.2% in Finland and 3.9% in Austria. In contrast, productivity growth in the steel industry during the period 1995-2009 was much lower, with some economies such as Japan, Finland and Italy experiencing a decline in productivity. The financial crisis in 2008-2009 is however likely to have contributed substantially to this decline.<sup>41</sup> In fact, Figure 23 shows that for some of the largest steel economies, productivity declined sharply after 2007.

**Figure 23. Evolution of productivity in basic metals industries during the 2000s**

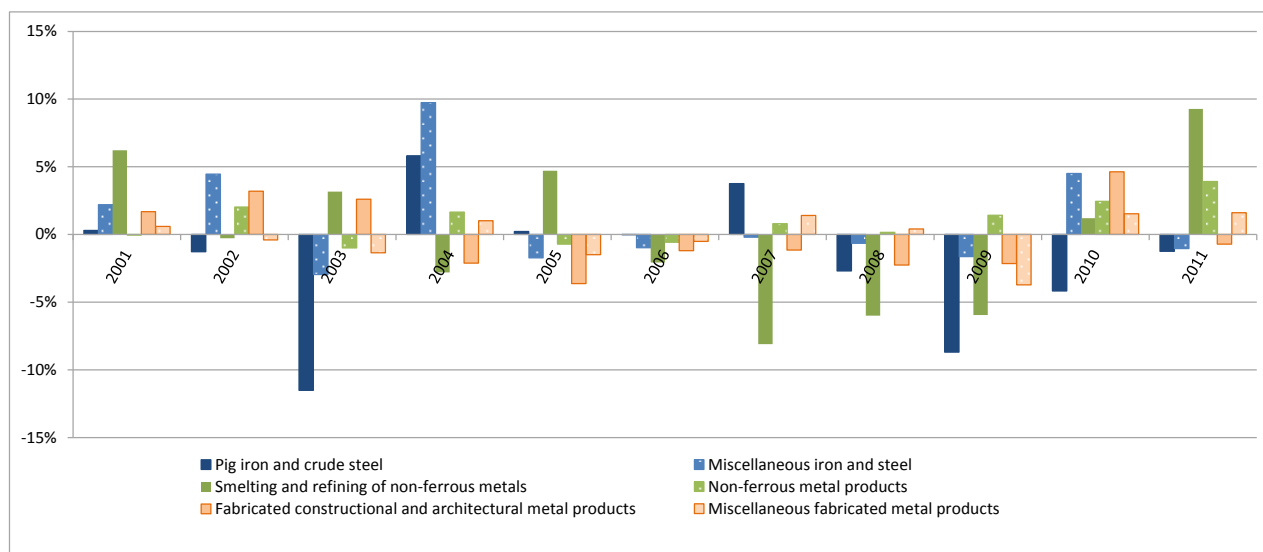
Multi Factor Productivity (value-added) in selected economies, 2001-2009 (2001=100)



*Note:* Industry is defined as an aggregate of basic metals (ISIC 4 industry code 24) and fabricated metal products (ISIC 4 industry code 25) due to data availability. The underlying data as well as explanatory documents can be found at the EUKLEMS project webpage: <http://www.euklems.net/>. Due to data availability, data are presented as changes and not levels, meaning that the analysis is not made based on productivity, but rather on how much productivity has changed.

*Source:* OECD calculations based on data from EUKLEMS.

There are however significant differences between the industries that are included in the broad classification used thus far (manufacture of basic metals and fabricated metal products). As an illustration, data from the Japan Industrial Productivity Database (JIP, 2014), collected and produced by RIETI, clearly shows that productivity growth in each year in the iron and steel industry is very different from that of non-ferrous metals or fabricated metal products (Figure 24).<sup>42</sup>

**Figure 24. MFP growth rate by industry in Japan, 2001-2011**

Note: Industry is defined according to the classification used by the Japan Industrial Productivity Database (JIP, 2014). Further information is available at JIP's webpage: <http://www.rieti.go.jp/en/database/JIP2014/>.

Source: OECD calculations based on data from the Japan Industrial Productivity Database (JIP, 2014).

There is, moreover, considerable heterogeneity in productivity levels (and growth) even within narrowly defined industries (e.g. Bartelsman and Doms, 2000; Syverson, 2011). In fact, even within the same company, different plants or production units will likely exhibit distinct productivity levels — see for example Collard-Wexler and De Loecker (2015) for a plant-level productivity analysis.<sup>43</sup>

#### 4.2. Productivity of steelmaking companies

A good understanding of the dynamics behind aggregate productivity growth in the steel industry requires a closer look at firm and/or plant-level data. This section relies heavily on recent OECD work on measuring and analysing productivity using firm-level data (Gal, 2013; OECD 2015h) described in Box 4.<sup>44</sup>

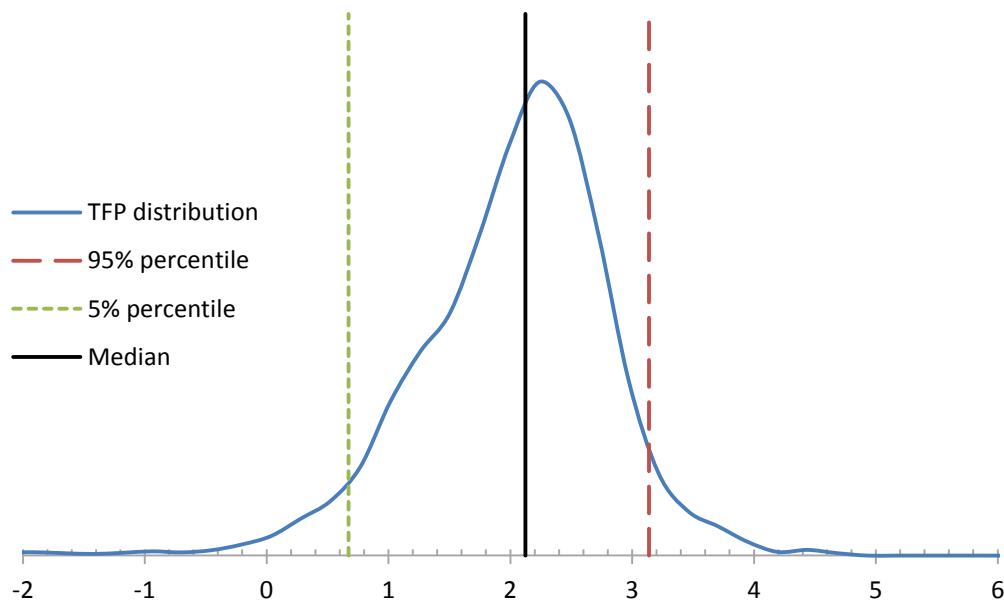
#### Box 4. Firm-level productivity data

The data on productivity presented in this section is obtained from the firm-level OECD productivity database (see Gal, 2013). The original source of company level information is the commercial ORBIS database provided by Bureau Van Dijk and was significantly transformed by Gal (2013) along a number of dimensions, including harmonisation to improve cross-country comparability. See Pinto Ribeiro et al., (2010) for a detailed description of the ORBIS database and of the cleaning and checking undertaken by the OECD in order to increase data quality and comparability (see also Ragoussis and Gonnard 2012). The measure of productivity used (multi factor productivity) was chosen to ensure that capital intensity is also controlled for. The calculation method adopted in this paper (Solow residual) is relatively easier to implement when compared to more refined multi factor productivity measures and entails lower data requirements, which means that the amount of usable data for analysis is larger. Please see Gal (2013) for further details on the productivity database as well as an overview of caveats in the use of the database, productivity measurement challenges, different productivity measures, and their advantages and disadvantages.

A selected subsample of companies from four different industries was extracted for industry comparison purposes. Industries are defined according to the 3-digit ISIC Rev. 4 classification available at <http://unstats.un.org/unsd/cr/registry/isic-4.asp>. The “Steel” industry is defined as “Manufacture of basic iron and steel” (C24.1), the remaining industries under the 2-digit class Manufacture of basic metals (C24) are classified here as “Basic metals (other than iron and steel)”. For comparative purposes, two additional 3-digit level industries are used in the analysis. The “Basic chemicals” industry is defined as “Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms (C201)”, while the “Plastics” industry is classified as “Manufacture of plastics products” (C222). This classification was then mapped to the NACE Rev 1.1 classification used in the productivity database.

Coverage of the sample with regards to the steel industry amounts to about 73% in terms of employment in the industry in 2006. The sample covers 19 of the 25 OECD member economies in the Steel Committee. The following economies are included in the sample: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Japan, Korea, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom, United States. Comparable data is available for the years 2001-2009. The sample only covers companies with 20 employees or more.

Figure 25 below illustrates the high heterogeneity in productivity levels in the steel industry. Even within the steel industry, there are considerable differences in productivity levels across firms. As shown in Figure 24, the steel productivity distribution exhibits fat tails<sup>45</sup> — i.e. the percentage of firms with very high\low productivity levels seems to be high. Data also suggest that productivity levels are more dispersed in the case of steel, when compared to other industries — the standard deviation for the distribution of steel companies’ multi factor productivity in 2006 is 0.84, above that of non-ferrous (0.74), chemicals (0.76) and plastics (0.71).<sup>46</sup> Indeed, the steel company in the 95th percentile of the productivity distribution in 2006 (vertical bar on the left) was 11.8 times more productive than that in the 5th percentile (vertical bar on the right).<sup>47</sup>

**Figure 25. Productivity distribution in the steel industry, 2006**

*Note:* Multi factor productivity (MFP) is defined as the Solow residual (see Gal, 2013 for further details) and is depicted here as the natural logarithm of the productivity level. Industry is defined at the 3-digit NACE Rev. 2. The chart plots the distribution of MFP using a kernel density estimate. The kernel density estimate gives an approximation of the probability density function of a given distribution (in the vertical axis) — up to a given point  $x$  in the horizontal axis, the area under this function provides the percentage of observations that have values that are lower or equal to  $x$ . The total area below each curve equals one. The vertical lines indicate the percentiles (5, 50 and 95) of the distribution.

*Source:* OECD calculations based on data from Gal (2013) and OECD (2015h).

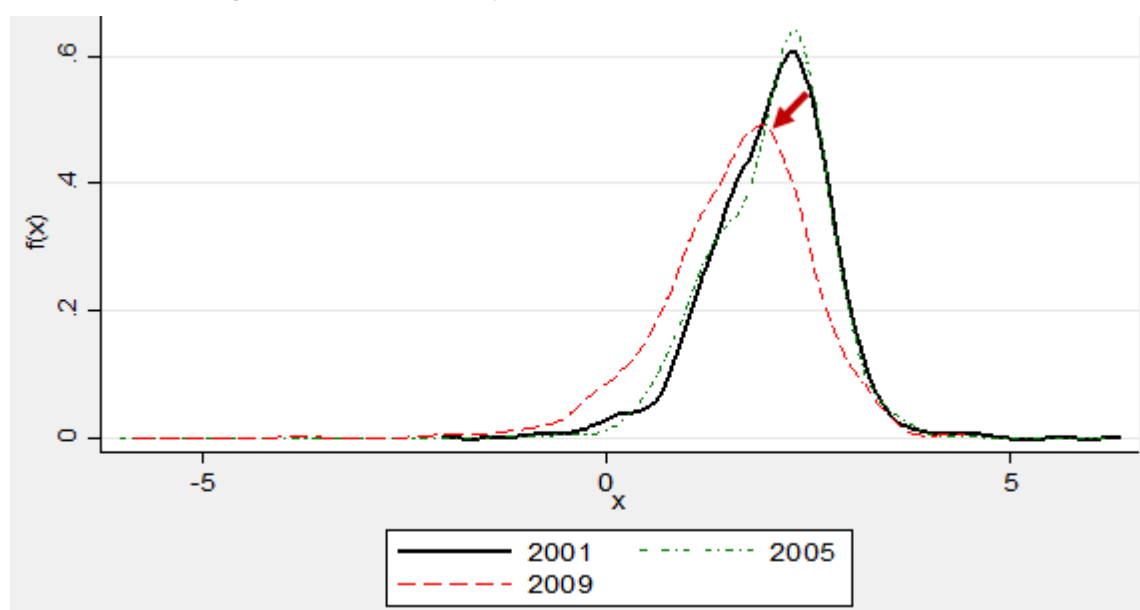
In practice, a higher dispersion of productivity for steelmaking companies compared to other industries suggests that, in the steel industry, there is considerable scope to reallocate resources from the less productive to the most productive firms/plants leading to productivity increases in the industry (OECD 2015g; Syverson, 2011).<sup>48</sup>

The analysis of productivity dispersion across companies (and plants) in the context of excess crude steelmaking capacity is particularly important to help identify the presence and extent of uneconomic capacity (OECD, 2015a). If uneconomic capacity can be defined as the existence of facilities that are not productive enough to be economically viable, then higher levels of dispersion in productivity implicitly indicate that the existence of uneconomic capacity is non-negligible.

Profitability and the dispersion in profitability rates as well as indebtedness levels are other possible indicators of the extent of uneconomic capacity. Results from recent OECD analysis (OECD, 2015i) also suggest that the levels of firm dispersion in profitability rates and debt levels has increased in 2007-2012, when compared to the downturn in the steel industry during the period 1997-2001. In this type of analysis, it is however necessary to take into the account the effects of policies. For example, companies that benefit from some type of public support may well exhibit higher productivity, profitability and/or lower debt levels. Data on public support measures are currently not available but the Secretariat is currently working towards increasing the knowledge and transparency about public support measures in the steel industry (c.f. OECD, 2015a; OECD, 2015c).

In order to verify whether the dispersion patterns are stable over time, it is important to compare the distribution of firm-level productivity in the steel industry in distinct points in time. Figure 26 below depicts the productivity distribution in 2001, 2005 and 2009 for steelmaking companies in the sample. Between 2001 and 2009, the distribution seems to have shifted to the left (lower productivity levels) along with an increase in dispersion (values are not so concentrated around the mean).<sup>49</sup> This suggests that the crisis in 2008-2009 has led to higher differences in productivity across steelmaking companies, mostly due to a reduction in productivity in a non-negligible number of firms. It is important to note that the decrease in productivity observed across companies in 2009 could be associated with a reduction in capacity utilisation rates. A closer look at the evolution of the top (and bottom) productivity performers in the next section provides additional information about where in the distribution and when in time productivity differences were more pronounced.

**Figure 26. Productivity distribution in 2001, 2005 and 2009**



Note: Multi factor productivity (MFP) is defined as the Solow residual (see Gal, 2013 for further details). Industry is defined at the 3-digit NACE Rev. 2.

Source: OECD calculations based on data from Gal (2013) and OECD (2015h).

#### 4.2.1. Frontier Productivity

Recent OECD work analysing productivity growth indicates that, despite a slowdown in aggregate productivity growth during the 2000s, productivity growth for firms at the “global productivity frontier” has remained robust (OECD, 2015h). For the purpose of this paper, “frontier” firms are defined here as the top 5% firms terms of productivity in each year and industry.<sup>50</sup> In 2006, frontier steelmaking companies accounted for 91 out of the 1 837 companies in the sample and were 4.26 times more productive than non-frontier firms.<sup>51</sup>

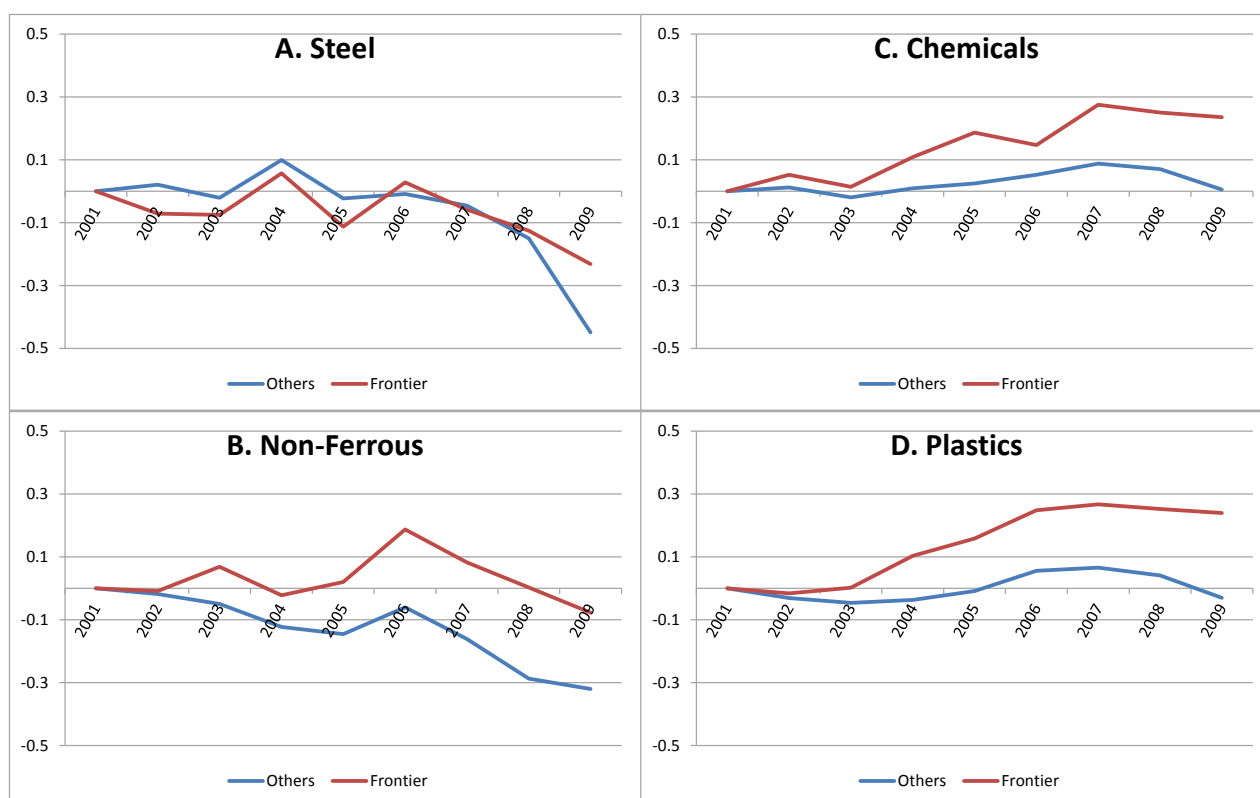
Figure 26 below depicts the evolution of productivity for frontier and non-frontier firms in a number of selected industries. Interestingly, the steel industry is the only case, among the sectors analysed, that does not show a clear decoupling of the frontier from non-frontier firms. In chemicals and plastics, the productivity of frontier firms grew faster than that of non-frontier firms, in line with the patterns for the whole manufacturing sector (cf. OECD, 2015h). On the contrary, firms in basic metals industries show a slowdown in productivity growth across the board.<sup>52</sup>

With regards to non-ferrous companies, there was an aggregate decline in productivity, but firms at the frontier appear to have been more resilient. Between 2001 and 2009, productivity in the non-ferrous industry decreased average annual rate of 0.8% for frontier firms, above the decline in productivity of non-frontier firms (3.2%).

Firms at the frontier in the steel industry do not appear to exhibit a significantly better productivity performance when compared to non-frontier firms. Panel A in Figure 27 does not show a decoupling in productivity growth between firms at the frontier and other firms except for the last year (2009). During the first decade of the 2000s, productivity growth was very close to zero, except during the initial years of the financial crisis where frontier firms seem to have held better than non-frontier firms. Productivity for frontier steelmaking companies declined at an average annual rate of 2.3%, while productivity for non-frontier steel firms declined at an average annual rate of 4.5%. In practice, this suggests that steel has been less dynamic during the 2000s, when compared to other industries.<sup>53</sup>

**Figure 27. Frontier productivity growth across industries**

Percentage difference in productivity levels from 2001 values (2001=0)



Note: Multi factor productivity (MFP) is defined as the Solow residual. Frontier firms are defined as the top 5% in MFP for each year and industry. Industry is defined at the 3-digit NACE Rev. 2. Further details can be found in Gal (2013) and OECD (2015h).

Source: OECD calculations based on data from Gal (2013) and OECD (2015h).

The extent to which steelmaking companies are able to persist at the productivity frontier is reflected in Table 3 below. Only 6.2% of frontier steelmaking companies are able to remain at the frontier of productivity, a value above that for the plastics industry but below the remaining selected industries and the average for the whole manufacturing sector. For illustrative purposes, results for the manufacturing sector indicate that 50.3% of firms are able to remain at the productivity frontier after one year, 30.9%

endure during two years and 14.1% persist at the frontier after 4 years (OECD, 2015h). This suggests that it is common for steelmaking companies to move in and out of the productivity frontier.

**Table 3. Persistence at the productivity frontier**

Industry	Percentage of firms persisting at the frontier after...			
	1 Year	2 Years	3 Years	4 Years
Steel	40.7%	20.4%	10.9%	6.2%
Basic Metals (non-ferrous)	41.3%	21.3%	11.1%	6.4%
... of which Aluminium	52.0%	28.2%	14.0%	6.4%
Basic Chemicals	43.1%	24.0%	15.1%	9.3%
Plastics	37.3%	16.7%	8.2%	4.4%
Cement, lime & plaster	60.9%	39.1%	25.8%	16.9%

*Note:* Frontier firms are defined as the top 5% in MFP for each year and industry. Industry is defined at the 3-digit NACE Rev. 2. Persistence at the frontier is measured in consecutive years at the frontier. Some firms may well be part of the frontier in one year, the next year be surpassed by other firms and then be part of the frontier again one (or more) year later.

*Source:* OECD calculations based on data from Gal (2013) and OECD (2015h).

#### 4.2.2. Laggard productivity

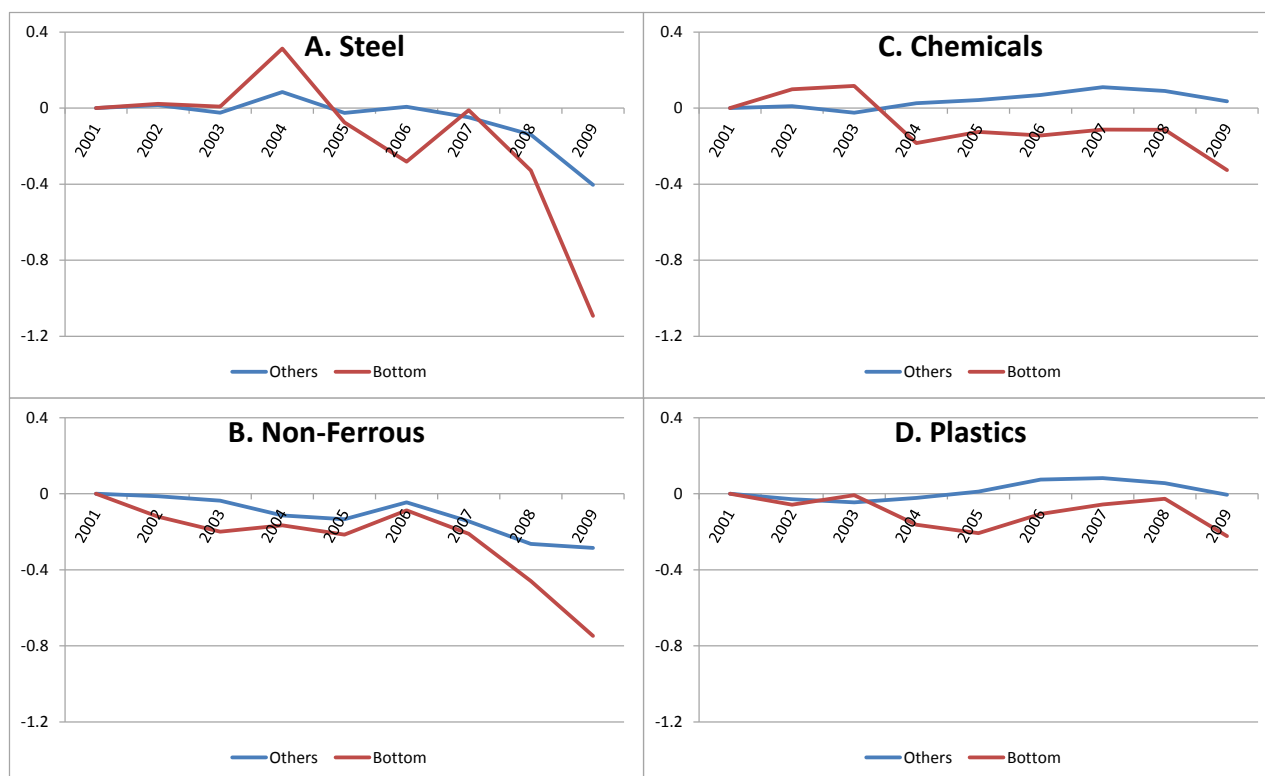
Interestingly, the differences in the evolution of productivity between frontier and non-frontier firms described in the preceding section appear to be smaller in steel than in other sectors. However, a higher dispersion of productivity for steelmaking companies compared to other industries is also found. Given this relatively high dispersion in productivity levels in the industry, it is therefore quite likely that larger differences in productivity are to be found at the bottom of the productivity distribution. Figure 26, showing the downward shift in the distribution, also suggest that movement at the bottom of the distribution over time is more pronounced than movement at the top of the productivity distribution.

Following the same logic used in the analysis of frontier firms, a similar analysis can be conducted with respect to the evolution of the lower end of the productivity distribution, provided some caution is taken in the interpretation of results.<sup>54</sup> Firms at the bottom 5% of the productivity distribution in each year and industry are defined here as “laggards”.

Figure 28 depicts the evolution of laggard firms in comparison to the remaining companies in the sample, across the four industries analysed.<sup>55</sup> While there is a sharp decrease in productivity of the least productive steelmaking firms during the 2008-2009 crisis, productivity of laggards in other industries exhibits a smoother decline. The productivity levels of laggards in the steel industry more than halved during the decade. Other steelmaking companies were however more resilient to the crisis than the laggards, exhibiting a productivity decrease at an average annual rate around 4%. Interestingly, the decline in productivity of laggards in other industries is still meaningful, but much smaller. For example, the decline for laggards in the chemicals industry (around 3.2%) was less pronounced than the productivity decline for non-laggards in the steel industry (4%).

**Figure 28. Laggard productivity growth across industries**

Percentage difference in productivity levels from 2001 values (2001=0)



Note: Multi factor productivity (MFP) is defined as the Solow residual. Laggard firms are defined as the bottom 5% in MFP for each year and industry. Industry is defined at the 3-digit NACE Rev. 2. Further details can be found in Gal (2013) and OECD (2015h).

Source: OECD calculations based on data from Gal (2013) and OECD (2015h).

Among different possibilities, there is an interesting tentative explanation — associated with the ability of less productive companies to exit the market — for the sharp decline in the average productivity of laggards in the steel industry that is worthwhile describing. If, in an efficient market, companies do not face significant barriers to exit, the average productivity levels of the group of least productive firms (those that are more likely to exit) can remain relatively stable in downturns (as the least productive firms eventually exit, firms with higher productivity become the new laggards). Therefore, by construction, the average productivity of the new laggards will be higher as compared to productivity of the exiting firms. If on the contrary, it is difficult for firms to exit, poorly performing companies will remain in the market and will drag average productivity of the laggards further down. Recent OECD work notes that the existence of high barriers to exit is an important factor that can result in higher differences from the worst performers to the frontier and also lead to lower aggregate productivity overall (OECD, 2015g). In fact, trapping resources in relatively small and low productivity firms can hinder the growth prospects of more innovative firms (Acemoglu et al., 2013).

Applying the above argumentation to the data observed in Figure 26 above suggests that, when compared to other industries, exit barriers might be higher in the steel market, given the substantial fall in average productivity of laggard steelmaking companies. A thorough analysis of exits in the steel and other industries would however be necessary to make any strong statements with this respect. A similar analysis using profitability instead of productivity could also help shed some light on the persistence of unprofitable firms in the market. Both streams of work are likely to be carried out by the OECD Secretariat in the foreseeable future.

## 5. Conclusion

In a context of low profitability of the steel industry (OECD 2015b) the amount of financial resources that are available to devote to innovation are scarce and should therefore be soundly used. Investments into R&D have drastically been reduced during the run up to the financial crisis and are slowly increasing. At the same time, patenting activity has been significantly reduced recently and, despite a significant share of inventions in steel technologies that can contribute to climate change mitigation, more could yet be done to increase the environmental performance of the industry.

The industry could realise large long-term benefits from investments into the research and development of new technologies and improved production processes, particularly those that can result in increased efficiency and productivity growth. Productivity levels are very heterogeneous amongst steelmaking companies, where a non-negligible number of firms could perform substantially better. While the productivity frontier in the steel industry does not seem to be very dynamic, evidence from the lower end of the distribution raises concerns on whether high barriers to exit might be in place, limiting the scope for reallocation of resources towards the most productive firms.

By providing a first look at innovation and productivity issues in the global steel industry, this paper raises more questions than answers. Future research is therefore warranted and could focus for example on furthering the understanding about the economic impacts of innovation efforts, both in terms of new quality products, more efficient use of resources and productivity as well as its impact upon trade, sustainability and the competitiveness in the steel sector. At this stage, it was not yet possible to separate breakthrough steelmaking technologies from incremental innovations. Further work with patents would be particularly important to deepen the understanding of technological change in steel and implications upon industry competitiveness. This work would also help identify technologies that are currently expanding rapidly and are likely to become important technological fields in the near future, including innovations that could strongly contribute to climate change mitigation. Finally, the work on productivity could be directly linked to the work on capacity, as it could provide insights on potential distortions in the market that allow uneconomic capacity to be maintained. The evidence shown in this paper indicates a need to further investigate exit barriers in the steel industry.

## NOTES

<sup>1</sup> The Innovation Policy Platform is available at [www.innovationpolicyplatform.org](http://www.innovationpolicyplatform.org). The different types of policy instruments, more or less effective depending on the industrial characteristics and country-specificities, are available at [www.innovationpolicyplatform.org/content/policy-instruments](http://www.innovationpolicyplatform.org/content/policy-instruments).

<sup>2</sup> The classification system suggested assigns industries into five broad classes depending on their R&D intensity: “high”, “medium-high”, “medium”, “medium-low” and “low”. For illustrative purposes, “high” and “medium-high” R&D intensity industries include for example air and spacecraft and related machinery (C303) and chemicals and chemical products (C20), respectively. Industries with lower R&D intensities include for example textiles (C13) classified as “medium-low” and construction (F41-F43) as “low”. It is also important to note that this classification should not be regarded as a classification that reflects technology or innovation, given the differences between R&D performance (input), innovation performance (output) and technological development.

<sup>3</sup> Please note that these results are in line with the R&D intensity classification system (OECD, 2015e).

<sup>4</sup> Compared to gross output, gross value added entails broader country coverage, is less sensitive to sector specific reliance on material inputs like raw goods and avoids potential double counting of output used in the same industry as an intermediate good. See OECD (2015e) for further details.

<sup>5</sup> During downturns when short-term cash needs are more pressing, firms may decide to reduce investments into R&D, notably if the returns on such investments (e.g. gains in efficiency or cost reductions) are only accrued over the longer run.

<sup>6</sup> Free cash-flow provides information on firms’ capacity to generate cash after investments and covering costs of replacing capital (depreciation and amortisation). It is the amount of cash that a firm generates and is available for either paying out dividends to shareholders or retaining as cash holdings for use in future periods.

<sup>7</sup> Voestalpine is currently running several research projects in over 20 countries, undertaken in cooperation with around 80 universities and research institutes. Please refer to the presentation made by Mr. Franz Androsch at the 78th Session of the Steel Committee, available at: [www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm](http://www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm); voestalpine Group’s website at: [www.voestalpine.com/blog/en/innovation-en/research-development-at-voestalpine/](http://www.voestalpine.com/blog/en/innovation-en/research-development-at-voestalpine/).

<sup>8</sup> The percentage of firms that engage in R&D is however very different across industries as a result of factors such as different technological trajectories, stage of development and market conditions.

<sup>9</sup> An overview of the impact of R&D and the role of knowledge-based capital can be found in OECD (2013d).

<sup>10</sup> In the short to medium term, innovations tend to increase a firm’s profitability (Geroski et al., 1993), but as other firms also compete on quality, the profit margins gained by a firm from its innovation are likely to be steadily eroded, provided that markets function efficiently.

<sup>11</sup> Available at: <https://www.steeluniversity.org/>.

- 12 Further information on OECD work on skills can be found at: <http://skills.oecd.org/>.
- 13 A recent OECD publication overviewed the key drivers of knowledge transfer between industry and higher education institutions, as well as policies that can help enhancing knowledge diffusion (OECD, 2013c).
- 14 See the presentation by Mr. Yasin Öcal at the 78th Session of the Steel Committee. Available online at: [www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm](http://www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm).
- 15 See the presentation by Dr. Gert Nilson at the 78th Session of the Steel Committee. Available online at: [www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm](http://www.oecd.org/sti/ind/steelcommittee78thsession11-12may2015.htm).
- 16 The White Book of Steel (World Steel Association, 2012) provides numerous examples in the different technologies used in modern steelmaking processes.
- 17 India, Venezuela, Iran, Mexico, and Russia are the main DRI producers.
- 18 According to the International Iron Metallurgy Association (IIMA), global production of hot briquetted iron and direct reduced iron is expected to almost double by 2025 as the growth of steelmaking using the electric arc furnace route is expected to continue.
- 19 Steelmakers in the region are replacing outdated open-hearth furnaces with BOF and EAF furnaces.
- 20 According to data from Worldsteel, continuous casting ratio in crude steel production reached 96.0% in 2013.
- 21 Inclusion particles are non-metallic impurities such as oxides, sulphides, or silicates, which affect the consistency of steel products.
- 22 The objective of patent systems is to foster innovation in the private sector, by allowing inventors to profit from their inventions. However, there may be negative effects in terms of competition and technology diffusion, as patents grant temporary monopolies in technologies and/or products.
- 24 Please note that the patent stock is a technology-based indicator that does not take into account production volumes. It therefore does not control for the size of the steel sector in each economy.
- 25 Please refer to the Annex for the corresponding steel products patent codes.
- 26 Please refer to the Annex for the corresponding steel-related processes patent codes.
- 27 It is also important to note that steelmaking companies may file patents in technological fields that are not related to steel, but these cases fall beyond the purpose of this paper.
- 28 For example, while a specific invention can be attributed to “Company X”, another invention might be attributable to the same company, but registered with the assignee name “Company X, Corp.” or with the name in the original language. In addition, patents may also be registered under individual names in the assignee field.
29. Please note that emissions intensity vary widely across regions and between companies.
30. In 2012, the sector emitted 2 552 Mt CO<sub>2</sub>, thus accounting for 31% of all industrial CO<sub>2</sub> emissions and 7.4% of global direct CO<sub>2</sub> emissions that year (see IEA, 2015). This includes emissions from blast furnaces and coke ovens, and excludes indirect emissions related to power generation. Please note that emission intensity varies across economies and companies.

31. Further information available at: [www.oecd.org/env/consumption-innovation/innovation.htm](http://www.oecd.org/env/consumption-innovation/innovation.htm).
32. Not all patents are equal, and methodologies such as adjusting patent counts for patent quality using citations have been frequently used to identify the "quality" of inventions. More recently, efforts have been made to use the information contained in patent documents to for the identification of breakthrough technologies. See Squicciarini et al. (2013) for an algorithm to identify breakthrough patents and Egli et al. (2015) for an analysis of different attributes of inventions and how they can contribute to the development of leading indicators to identify breakthrough innovations in climate change mitigation technologies.
33. Please refer to the Annex for a detailed description of the approach used to investigate the patenting activity of steelmaking companies.
34. In this technological field, the entity in the first position scored 7.8, while the entity in the 100th position scored 1.2.
35. On the one hand, there is very limited scope for further emission reduction through efficiency improvement. With reduction of iron ore being the largest energy-intensive step for the production of primary steel, there is limited energy savings potential when comparing current state-of-the-art blast furnaces to practical minimum energy requirements. On the other hand, the use of coke and limestone as fluxing and reducing agents at blast furnaces results in process emissions (thought to be around 6% of total emissions) that cannot be avoided via energy efficiency or alternative fuels, but which can be mitigated using CCS.
36. The Y02C tag covers a set of technologies related to the "Capture, storage, sequestration or disposal of greenhouse gases (GHG)" that include not only capture and storage of CO<sub>2</sub> but also other pollutants such as nitrous oxide. Separation was first done for other reasons in the chemical industry. The tagging system has been designed such as to avoid the "tagging" of such cases, focusing on those of direct relevance to CCS. Even though a specific tag exists for CCS technologies (Y02C 10, "CO<sub>2</sub> capture or storage"), the low number of observations per year that pertain to steel in the subcategories of Y02C is not adequate for analysis. The patent counts in Y02C are already very low so further disaggregation would limit the scope of analysis. It should nevertheless be noted that, within steel-related Y02C, a considerable percentage of patents should be related to CCS technologies.
37. Factors controlled for included an incentive plan, some investments and cumulative learning. The plant used standard equipment, implying that there was no room for improvements through R&D.
38. Data requirements for computation of labour productivity are relatively low, when compared to multi-factor productivity. See OECD (2001) and Gal (2013) for an overview.
39. Please note that a more refined measurement of output-based multi factor productivity, accounting for intermediate inputs, is not applied in Section 4.2 due to data constraints. See OECD (2001) and Gal (2013) for a detailed discussion of the different productivity measures and associated challenges.
40. The industry aggregation to basic and fabricated metal is a consequence of limited availability of disaggregated industry prices. Country-level productivity data presented here should therefore be regarded with some caution as both fabricated metals and manufacture of non-ferrous metals are included.
41. The (unweighted) country average decline of multi factor productivity was about 6.8% in 2008 and 14.3% in 2009, after positive growth rates of 3.8% in 2006 and 1% in 2007.
42. Country level productivity data that is disaggregated down to the Iron and Steel industry is very rare to find and, to the author's knowledge, the JIP database is the only source providing such detailed and useful information.

43 An analysis of productivity at the plant level is particularly important in the case of the steel industry, given the distinct production processes employed (e.g. BOF versus EAF) and the different combinations of inputs that may be utilised — e.g. BOF would typically be more capital-intensive; different shares of raw material inputs can be utilised even within the same technology. The data requirements for this type of analysis are enormous and at this stage, data limitations render the analysis unfeasible.

44 The authors are very grateful to Peter Gal, Chiara Criscuolo and Dan Andrews for sharing the productivity data as well as for their comments and suggestions on earlier versions of this paper. Any remaining errors are ours.

45 Please note that the variable plotted is the natural logarithm of the productivity level.

46 Tests confirm that the difference between the variance for the steel distribution is statistically different than those of other industries.

47 To provide some insights on the magnitude of dispersion, Syverson (2004) analyses productivity dispersion at the plant level in 4-digit manufacturing industries in the United States and finds that companies in the 95th percentile of the multi factor productivity distribution are, on average for manufacturing industries, about two to four times more productive than firms in the 5th percentile, depending on the multi factor productivity measurement approach used.

48 Another possible interpretation of high levels of dispersion relates to when industries experience a great deal of experimentation of new breakthrough technologies, which may not be as plausible for the steel sector as it could be for other sectors such as electronics in the present days. Collard-Wexler and De Loecker (2015), focusing on the productivity effects of the introduction of the minimill, find significant differences in productivity levels between integrated plants and minimills in the United States in the 1960s, but then a fast catch-up (between 1963 and 2002) of productivity in integrated producers by means of reallocation of resources towards the most productive integrated plants and the exit of less efficient integrated producers, typically those operating for a lower quality segment of the market.

49 Average productivity for steelmaking companies in 2009 more than halved when compared to 2005 (66%) or to 2001 (64%). The standard deviation in steelmaking companies' productivity in 2009 was 0.97, much larger (and statistically different) from that in 2005 (0.79) or in 2001 (0.77).

50 This is one of the typical approaches used to define productivity frontier, however, other definitions could be used (e.g. top 50 firms). Concerns related to the high variation in the size of the sample of firms available in ORBIS (increases exponentially in the later years) are partially mitigated because a large proportion of the new company observations do not include sufficient data for the calculation of multi factor productivity. Therefore the changes in sample are relatively small. The analysis is indeed robust to using a balanced panel of firms — i.e. including only those that for which information are available in all the years during 2001-2009.

51 Please note that productivity is measured in logs, thus the difference in productivity levels between frontier and non-frontier firms equals  $\exp(1.45)=4.26$  times.

52 Again, the reduction in capacity utilisation rates, notably in the steel sector, can help explain this lower productivity performance.

53 Some results could be driven by the structure of the data sample — a non-negligible number of companies may not be observed in the sample for certain years and then reappear again. As a robustness test, the same analysis was performed with a reduced sample of firms that were observed in all the years from 2001 to 2009 (balanced panel). The interpretation of the results using a balanced panel remains unchanged.

54. The analysis of laggards in this fashion is often avoided due to the (under)representativeness of smaller (usually less productive) firms in firm-level datasets, notably in ORBIS (see Gal, 2013 for a detailed discussion). However, the assumption of under representativeness of less productive firms in this analysis — which is not necessarily the case given the typically large size of steelmaking companies — would suggest that the decrease in productivity of the real group of less productive firms (and not the sample used here) would likely be even more pronounced. Therefore, the implications related to the sharp decrease in productivity of the less productive firms in the steel industry still hold.
55. Please note that productivity growth for laggards can exceed that of other firms in a given year, even when laggards are determined on a rolling basis annually (i.e. the composition of the group of laggard firms may change every year). This is the case when the productivity growth for laggards in that year is higher than for the remaining firms. In such case, the lower left end of the distribution will shift to the right, while the remaining central and upper right end of the distribution will remain relatively similar. In these cases, there will be some degree of convergence of productivity levels, as the laggards catch up. For example, this is visible by comparing the distribution of MFP of steelmaking companies in 2001 and 2005 (Figure 26) and the productivity growth of laggards in Panel A of Figure 28. Again, movements at the bottom of the distribution over time seems to be more pronounced than movement at the top of the productivity distribution.

## REFERENCES

- Acemoglu, D., U. Akcigit, N. Bloom and W. Kerr (2013), “Innovation, Reallocation and Growth”, *NBER Working Papers*, No. 18993.
- Adams, Walter and Joel Dirlam (1966), “Big Steel, Invention, and Innovation”, *The Quarterly Journal of Economics*, Vol. 80, No. 2, pp. 167-189.
- AMM (2013), “World and US Production of DRI and HBI”, American Metal Market, available at: [http://www.amm.com/EventAssets/25/5847/elements/AMM\\_DRI\\_MM\\_2013\\_PDF\\_Report\\_1D\\_opt.pdf](http://www.amm.com/EventAssets/25/5847/elements/AMM_DRI_MM_2013_PDF_Report_1D_opt.pdf).
- Andrews, D., C. Criscuolo and C. Menon (2014), "Do Resources Flow to Patenting Firms?: Cross-Country Evidence from Firm Level Data", *OECD Economics Department Working Papers*, No. 1127, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/5jz2lpmk0gs6-en>.
- Bartelsman, Eric J. and Mark Doms (2000), “Understanding Productivity: Lessons from Longitudinal Microdata,” *Journal of Economic Literature*, Vol. 38, No. 3, pp. 569–594.
- Bennett, Simon J., and Wolfgang Heidug (2014), "CCS for Trade-exposed Sectors: An Evaluation of Incentive Policies." *Energy Procedia*, 63: pp. 6887-6902.
- de Carvalho, A. and N. Sekiguchi (2015), "The structure of steel exports: Changes in specialisation and the role of innovation", *OECD Science, Technology and Industry Working Papers*, No. 2015/07, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/5jrxfmstf0xt-en>.
- Collard-Wexler A. and J. De Loecker (2015), “Reallocation and Technology: Evidence from the U.S. Steel Industry”, *American Economic Review*, 105(1): 131–171.
- Czarnitzki, D., and H. Hottenrott (2011), “Financial constraints: Routine versus cutting edge R&D investment”, *Journal of Economics & Management Strategy*, 20(1): 121–57.
- D'Costa, Anthony (2003), “The Global Restructuring of the Steel Industry: Innovations, Institutions and Industrial Change” Routledge Studies in International Business and the World Economy, Taylor & Francis, 2003.
- Egli, F., N. Johnstone and C. Menon (2015), "Identifying and inducing breakthrough inventions: An application related to climate change mitigation", *OECD Science, Technology and Industry Working Papers*, No. 2015/04, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/5js03zd40n37-en>.
- Emi, Toshihiko (2015), “Steelmaking Technology for the Last 100 Years: Toward Highly Efficient Mass Production Systems for High Quality Steels”, *ISIJ International*, Vol. 55 (2015), No. 1, pp. 36–66.
- EPO (2013), “Finding sustainable technologies in patents”, European Patent Office, Munich. Available at: [documents.epo.org/projects/babylon/eponet.nsf/0/6e41c0df0d85c0acc125773b005144de/\\$FILE/sustainable\\_technologies\\_brochure\\_en.pdf](http://documents.epo.org/projects/babylon/eponet.nsf/0/6e41c0df0d85c0acc125773b005144de/$FILE/sustainable_technologies_brochure_en.pdf).

- Fruehan, R., D. Cheij and D. Vislosky (1999), "Steel" in D. Mowery (ed.), *U.S. Industry in 2000: Studies in Competitive Performance*, National Academy of Sciences, Washington, DC.
- Gal, P. N. (2013), "Measuring Total Factor Productivity at the Firm Level using OECD-ORBIS", OECD Economics Department Working Papers, No. 1049, OECD Publishing. <http://dx.doi.org/10.1787/5k46dsb251s6-en>
- Geroski, P.A., S Machin and J. Van Reenen (1993), "The Profitability of Innovating Firms", *RAND Journal of Economics*, 24(2), pp. 198-211
- Hall, B. H., A. B. Jaffe, and M. Trajtenberg (2005), "Market Value and Patent Citations," *Rand Journal of Economics*, 36, 16–38
- Hall, B. H. and J. Lerner (2010), "The Financing of R&D and Innovation", in B. H. Hall, and N. Rosenberg, (eds.) *Handbook of the Economics of Innovation*, Amsterdam: Elsevier. pp:610-38.
- Haščič, I. and M. Migotto (2015), "Measuring environmental innovation using patent data", *OECD Environment Working Papers*, No. 89, OECD Publishing, Paris, <http://dx.doi.org/10.1787/5js009kf48xw-en>.
- Hendel, I. and Spiegel, Y. (2014), "Small Steps for Workers, a Giant Leap for Productivity," *American Economic Journal: Applied Economics*, Vol 6, Issue 1 A.
- Hulten, C. R. (2001), "Total Factor Productivity. A Short Biography," in *New Developments in Productivity Analysis: National Bureau of Economic Research, Inc*, pp. 1–54.
- IEA (2014), *CCS 2014 - What Lies in Store for CCS*, International Energy Agency Insight Publications, 2014 Available at: <https://www.iea.org/publications/insights/insightpublications/>.
- IEA (2015), *Energy Technology Perspectives 2015*, OECD Publishing, Paris. DOI: [http://dx.doi.org/10.1787/energy\\_tech-2015-en](http://dx.doi.org/10.1787/energy_tech-2015-en).
- JIP (2014), "Japan Industrial Productivity Database 2014", Research Institute of Economy, Trade and Industry (RIETI). Available at: <http://www.rieti.go.jp/en/database/JIP2014/>.
- Laitner, J., M. Ruth and E. Worrell (2001), "Incorporating the Productivity Benefits into the Assessment of Cost effective Energy Savings Potential Using Conservation Supply Curves", Conference Paper, ACEEE's 2001 Summer Study on Energy Efficiency in Industry Proceedings, 1, Issue 8.
- Luiten, E., H. van Lente and K. Blok (2006), "Slow Technologies and Government Intervention: Energy Efficiency in Industrial Process Technologies", *Technovation*, Vol. 26, Elsevier.
- Luiten, E. and K. Blok (2003), "Stimulating R&D of Industrial Energy-Efficient Technology; The Effect of Government Intervention on the Development of Strip Casting Technology", *Energy Policy*, Vol. 31, Elsevier.
- Manning, C. and R. Fruehan (2001), "Emerging Technologies for Iron and Steelmaking", *Journal of Minerals, Metals and Materials Society*, Vol. 53, No. 10.
- Matsumiya, T. (2005), "Steel Research and Development in the Aspect for a Sustainable Society", *Scandinavian Journal of Metallurgy*, Vol. 34, Blackwell Publishing.

- Midrex (2013), “World Direct Reduction Statistics”, available at: [http://www.midrex.com/pdfs/MIDREX\\_World-DRI-Stats.pdf](http://www.midrex.com/pdfs/MIDREX_World-DRI-Stats.pdf).
- Nil, Jan (2005), “Technological Competition, Time, and Windows of Opportunity: The Case of Iron and Steel Production Technologies”. IN: Sartorius, C. and Zundel, S. (eds.): *Time Strategies, innovation and environmental policy*, Edward Elgar, Cheltenham, pp. 255-286.
- OECD (2001), “Measuring Productivity, OECD Manual,” Technical report, Paris: Organisation for Economic Co-operation and Development.
- OECD (2009), *OECD Patent Statistics Manual*, OECD Publishing. doi: 10.1787/9789264056442-en.
- OECD (2010a), *Measuring Innovation: A New Perspective*, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/9789264059474-en>.
- OECD (2010b), “Climate change policy and iron and steel industry 2010”, internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2010)17.
- OECD (2011), *Invention and Transfer of Environmental Technologies*, OECD Studies on Environmental Innovation, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/9789264115620-en>.
- OECD (2012a) “The future of the steel industry: selected trends and policy issues”, internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2012)12.
- OECD (2012b), “State Ownership in the Steel Industry: Issues for Consideration”, internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2012)6.
- OECD (2012c), *Energy and Climate Policy: Bending the Technological Trajectory*, OECD Studies on Environmental Innovation, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/9789264174573-en>
- OECD (2013a) “Evaluating the current state of the steel industry: Work in progress”, internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2013)19.
- OECD (2013b), *Supporting Investment in Knowledge Capital, Growth and Innovation*, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/9789264193307-en>.
- OECD (2013c), “Knowledge transfer and exchange: drivers and indicators”, internal working document, Directorate for Science, Technology and Industry, DSTI/STP/RIHR(2013)6.
- OECD (2013d), “The strategic public-private partnerships for innovation: final report”, OECD Science, Technology and Industry Policy Papers No. 26.
- OECD (2014a), “Proposal for measuring effective capacity”, internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2014)17.
- OECD (2014b), “Open educational resources as a catalyst for innovation in education - Evidence of impacts and remaining challenges”, internal working document, Directorate for Education and Skills, EDU/CERI/CD/RD(2014)12.

- OECD (2015a), "Excess Capacity in the Global Steel Industry and the Implications of New Investment Projects", *OECD Science, Technology and Industry Policy Papers*, No. 18, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/5js65x46nxhj-en>.
- OECD (2015b), "Recent market developments in the global steel industry", internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2015)1.
- OECD (2015c), "Public financial support to new investments in the global steel industry: Work in progress", internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2015)2.
- OECD (2015d), *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/9789264239814-en>.
- OECD (2015e), "The R&D intensity of economic activities in OECD countries: Proposal for a new classification for industry and services", internal working document, Directorate for Science, Technology and Industry, DSTI/EAS/STP/NESTI(2015)9.
- OECD (2015f), "Upgrading in GVCs: The role of innovation", internal working document, Directorate for Science, Technology and Industry, DSTI/IND(2015)4.
- OECD (2015g), *The Future of Productivity*, OECD Publishing, forthcoming.
- OECD (2015h), "The future of productivity: Frontier firms, technology diffusion and public policy: Micro evidence from OECD countries", internal working document, Directorate for Science, Technology and Industry, DSTI/IND(2015)1/ANN2.
- OECD (2015i) "Evaluating the financial health of the steel industry", internal working document, Directorate for Science, Technology and Industry, DSTI/SU/SC(2015)12.
- Pinto Ribeiro, S., S. Menghinello and K.D. Backer (2010), "The OECD ORBIS Database: Responding to the Need for Firm-Level Micro-Data in the OECD", OECD Statistics Working Papers, 2010/1, OECD, Paris.
- Pizer, W. A. and D. Popp (2008), "Endogenizing technological change: Matching empirical evidence to modeling needs", *Energy Economics*, 30(6):2754–2770.
- Popp, D., T. Hafner, and N. Johnstone (2011), "Environmental policy vs. public pressure: Innovation and diffusion of alternative bleaching technologies in the pulp industry", *Research Policy* 40 (2011) 1253–1268.
- Ragoussis, A., and E. Gonnard (2012), "The OECD-ORBIS Database Treatment and Benchmarking Procedures", internal working document, OECD Statistics Directorate.
- Silva, F. and C. Carreira (2012), "Do financial constraints threaten the innovation process? Evidence from Portuguese firms", *Economics of Innovation and New Technology*, Vol. 21, Iss. 8.
- Squicciarini, M., H. Dernis and C. Criscuolo (2013), "Measuring Patent Quality: Indicators of Technological and Economic Value", OECD Science, Technology and Industry Working Papers, No. 2013/03, OECD Publishing, Paris. DOI: <http://dx.doi.org/10.1787/5k4522wkw1r8-en>.

- Stubbles, J. (2007), “Operating and Environmental Benefits From the Production and Use of Hot Briquetted Iron”, *Iron and Steel Technology*, Vol. 4, No. 2.
- Syverson, Chad (2004), “Product Substitutability and Productivity Dispersion”, *The Review of Economics and Statistics*, Vol. 86, No. 2, pp. 534–550.
- Syverson, Chad (2011), “What Determines Productivity?”, *Journal of Economic Literature*, Vol. 49, No. 2, pp. 326–65.
- World Steel Association (2012) “The white book of steel” World Steel Association, Brussels. Available at: <http://www.worldsteel.org/publications/>.
- World Steel Association (2013), “Steel's contribution to a low carbon future”, World Steel Association Position Paper, Brussels. Available at: <http://www.worldsteel.org/publications/position-papers.html>.
- World Steel Association (2015), “Sustainable steel: Policy and indicators 2015”, World Steel Association, Brussels. Available at: <http://www.worldsteel.org/publications/>.
- World Steel Association (2014b), “Addressing climate change through technology transfer and research”, World Steel Association Fact Sheet, Brussels. Available at: <http://www.worldsteel.org>.
- Veefkind, V., Hurtado-Albir, J., Angelucci, S., Karachalios, K., & Thumm, N. (2012) “A new EPO classification scheme for climate change mitigation technologies”, *World Patent Information*, 34(2): 106–111.

## ANNEX. IDENTIFYING STEEL PATENTS

### *Data source*

Patent data used in this paper was extracted from the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT) and is based on the Cooperative Patent Classification (CPC).<sup>A.1</sup> The CPC is a classification system, jointly developed by the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO). The CPC provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. The legal basis for the international patenting classification system is provided by the Patent Cooperation Treaty (PCT). The PCT is an international treaty, administered by the World Intellectual Property Organization (WIPO), between more than 140 Paris Convention countries. The PCT makes it possible to seek patent protection for an invention simultaneously in each of a large number of countries by filing a single “international” patent application instead of filing several separate national or regional patent applications. The granting of patents remains under the control of the national or regional patent Offices.

### *A procedure to identify steel-related patents*

Identifying steel-related patents is not straightforward since patents are classified according to technological fields and not products or industries. A stepwise process was followed and included the following steps:

1. Identify 3-digit codes that can potentially be related to steel.
2. Within the identified codes, exclude 6-digit codes that are clearly not related to steel.
3. For each remaining code after (2), analyse the prevalence of steel companies as applicants using keywords and selected company names.
4. Exclude codes that do not have steel companies as applicants as defined by (3).
5. Group all remaining codes under three different categories according to their relevance for steel:
  - a. Set A: Codes that are confirmed as steel technologies.
  - b. Set B: Codes for technologies that are mainly used in steel, but can include applicants from other industries (e.g. non-ferrous metals).
  - c. Set C: Codes for other technologies that while relevant for steel and patented by steel companies reflect technologies mostly used in other industries (e.g. transferring or trans-shipping at storage areas, railway yards, harbours, code B65G63). These are excluded from the present analysis.<sup>A.2</sup>
6. Patent data are extracted for sets A and the reunion of sets A and B. The former does not include so much noise in terms of patents that may not be related to steel, but misses a number of important inventions. The latter provides a broader set of codes that are closely related to steel but can include a relatively small number of inventions that are not steel related. Patents for codes belonging to set C are deemed too noisy and are not extracted.
7. Steel related patents are identified as the Set AB, i.e. comprises all the codes included in the Sets A and B in the Table below. A number of codes potentially related to steel are excluded.

8. Equivalent patents were dropped to avoid double counting. In the cases where patents included more than one company/applicant patent shares were computed, reflecting the number of co-patenting applicants (fractional counts). A simple equal share approach is used, whereby a patent with for example applicants from three different countries is assigned equal shares between them — i.e. each country will be assigned a fractional count of 0.33 for that patent.
9. Patent applications can be filed in different patent offices at the same time and by the same entity. Again, to avoid double counting, patent equivalents are dropped and country and date are assigned on a priority basis — i.e. the first patent.
10. Finally, to calculate the stock of inventions at a given point in time, a standard approach is used, based on a fixed depreciation rate. The patent stock is calculated as the cumulative sum of the depreciated yearly patent count, discounted at a 15% rate of depreciation rate per year (Andrews et al, 2014; Hall et al., 2005). Depreciation is meant to control for the obsolescence of older technologies. If the stock of patents was not depreciated, the present value of a new patent would equal the present value of a patent in the 19<sup>th</sup> century.

The European Patent Office together with environment experts has developed a tagging system of patents related climate change mitigation (Y02 tag; see Veeffkind et al., 2012). The relevant environmentally related patents for steel are obtained through the CPC code Y02 “Technologies or applications for mitigation or adaptation against climate change”. Steel patents related to the environment are those resulting from the intersection of sets AB and Y02.<sup>A.3</sup>

The final list of codes used is provided in the Table below. Delegates are welcome to provide corrections to the identified codes as well as suggestions on how to refine this procedure. The codes identified as steel related are then combined with other codes that may be of interest for the purpose of analysis (e.g. environmentally related patents, see Section 3). Finally, each extraction provides the number of patents (patent counts) by applicant’s country and year.

#### *Identifying steel-related patents by steelmaking companies*

In order to identify the top patenting steelmaking companies, the following procedure was used in this paper:

1. Detailed information including the name of assignees of each patent was retrieved from PATSAT. Detailed extractions were only carried out for steel related technologies (set AB), low carbon steel related technologies (intersection of set AB and Y02) and steel related technologies in capture and storage of greenhouse gases (intersection of set AB and Y02C), for resource-intensity motives.
2. All steel-related patent assignees were ranked according to their patent stock in 2012 and the top 100 selected.
3. From these top 100 assignees, steelmaking companies were identified manually by comparing the assignee name to existing steelmaking companies and removing any entity whose major economic activity is not steelmaking.
4. Duplicates in the name of the company were merged computationally, but issues with remaining differences in names were addressed manually.
5. The resulting steelmaking companies, along with their respective 2012 patent stock scores are used in the analysis. However, other entities may be picked amongst the non-steelmaking excluded assignees for exemplificative purposes.

The authors recognise that this approach may still leave room for some bias, namely as a result of the exclusion of a large share of entities patenting in the selected technological fields (in some cases more than 100 thousand entities), as a result of the selection of the top 100 assignees. However, the patenting activity of the excluded assignees is considerably lower, as most of the patents are concentrated in the top 20-50 entities, thus any biases are expected to be minimal.

All patent data extractions were performed by Laurent Moussiegt, to whom the authors are very grateful for his time and patience.

**Annex Table. Steel-related patent codes**

SetA	SetB				Other
C21B	B21B	C10B3	C22B3	F27B1	<b>Environmentally-related</b> Y02
C21C	B21C	C10B5	C22B5	F27B3	
C21D3	B22D1	C10B7	C22B9	F27B5	<b>Carbon Capture</b> Y02C
C21D6	B22D2	C10B9	C22C45	F27B7	
C21D7	B22D3	C10B21	C22C47	F27B9	<b>Sections</b> B21B1/08 B21B1/082 B21B1/085 B21B1/088 B21B1/09 B21B1/092 B21B1/095 B21B1/098
C21D8	B22D5	C10B25	C22C49	F27B11	
C21D9	B22D7	C10B27	C23C2	F27B15	
C22B1	B22D9	C10B29	C23C4	F27B17	
C22B4	B22D11	C10B31	C23C6	F27B19	
C22C38	B22D13	C10B33	C23C8	F27B21	
	B22D15	C10B35	C23C10	F27D1	
	B22D17	C10B37	C23C12	F27D3	
	B22D18	C10B39	C23C14	F27D7	
	B22D19	C10B41	C23C16	F27D11	
	B22D23	C10B43	C23C22	F27D13	<b>C-Rolled</b> B21B1/28 B21B1/36
	B22D25	C10B45	C23C24	F27D15	
	B22D27	C10B47	C23C26	F27D17	<b>Alloy</b> B21B3/02 C22C38 C21C7/00
	B22D29	C10B49	C23C28	F27D19	
	B22D30	C10B53	C23C30	F27D21	<b>HDG</b> C23C2/06  <b>Production stages</b> <i>Ironmaking</i> C21B <i>Steelmaking</i> C21C <i>Rolling</i> B21B <i>Product</i> B21C
	B22D31	C10B55	C23D3	F27D25	
	B22D33	C10B57	C23D5	F27D27	
	B22D35	C21D1	C23F1	F27D99	
	B22D37	C21D5	C23F3	G01N33/20	
	B22D39	C21D10	C23F11	G01N3	
	B22D41	C21D11	C23F13		
	B22D43		C23F15		
	B22D45		C23F17		
			C23G1		
			C23G3		
			C23G5		

Note: Product specific patents identifying section, cold-rolled, alloy and hot dip galvanized products are also used in de Carvalho and Sekiguchi (2015) to calculate an indicator of revealed technological advantage.

- A.1 Detailed information about PATSTAT is available at:  
<http://www.epo.org/searching/subscription/raw/product-14-24.html>
- A.2 Even though technologies such as those classified under B65G (Transport or storage devices) or G01N (Investigating or analysing materials by determining their chemical or physical properties) are not directly related to the steelmaking process and steel products, they can significantly affect the steel industry. Specifically, while new technologies classified as B65G can increase the efficiency in transportation and storage of materials during the production process, technologies under G01N may provide innovations that can be translated into higher quality steel products.
- A.3 Further information on the Y tag is available at:  
<http://www.cooperativepatentclassification.org/cpc/scheme/Y/scheme-Y.pdf>.