Abstract

The case studies carried out in this paper investigates the innovative heuristics of the two leading EU firms in the robotics sector (KUKA and COMAU). The investigation employs an evolutionary perspective and a systems approach to examine a set of derived patent-based measures that explores firm behavior in technological knowledge search and accumulation. These examinations are supplemented by analyses of the firms' various historical archives on firm strategies and prevailing economic contexts at select periods in time.

Our investigation indicates that while these enterprises maintain outward-looking innovative propensities and maintain a diversified knowledge base, they tend to have a higher preference for the continuity and stability of their existing technical knowledge sets. The two company studies exhibited partially different responses to the common and on-going broader change in the robotics industry (i.e. emergence of artificial intelligence and ICT technologies in robotics applications), with KUKA being more outward-looking than COMAU. Furthermore, internal restructuring, economic shocks, and firm specificities were stronger catalysts of changes than external technology-based stimuli.
Looking forward through the past: An investigation of the evolution of robotics firms’ innovation strategies

Preliminary Draft – February 2019
I. Introduction

Robotics has significantly advanced since the first mechanical systems were conceived. Several but related technological breakthroughs in engineering, computer science, information technology, and related sciences have expanded the robots’ value proposition. In most recent years, the continued development of more advanced technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), are providing new possibilities that may revolutionize current industry (Estolatan, et al. 2018).

However, defining a robot remains a difficult challenge. As Joe Engelberger, the visionary of the industrial robot, once put, “I can’t define a robot, but I know one when I see one.” Various technical factors confound the task (Wilson, 2015) and different informants may provide their own definition (Pearson, 2015). Nonetheless, it is a challenge of paramount importance in the contemporary landscape because of the increasing role that such machines play in the future of production. Robotics is envisioned to be one of the main drivers of digital manufacturing, an environment that promises to deliver not only automated but also intelligent modes of production (Schwab, 2017); they are regarded as the exemplar ‘physical’ component in the factory of the future.

Unsurprisingly, robots are now at the center of the conversation regarding next-generation manufacturing. Much of this excitement in the public revolves around either the fascination on newer-generation robots’ capabilities (such as, interactivity, autonomy, and intelligence) or the disapproval on its likeliness to replace existing jobs. However, there is a notable absence of inquiry regarding the true capabilities of those expected to deliver these machines, which are the robot companies themselves. The ‘black boxes’ themselves are often presumed to continuously remain innovative and competitive (Violino, 2016).

This paper intends to fill the gap by studying the innovative behavior of the two top European robotics firms (KUKA and COMAU) and the developments within the broader sector. Our objective is to gain insights regarding these organizations’ probable responses to their contemporary environment. Is there historical antecedence to validate the expectation that robotics companies at large can easily deliver radical innovations? Can they be expected to truly revolutionize manufacturing? Answers to such questions may help explain why development and innovation in digital manufacturing-related disciplines remain captive within select institutions and regions.

We rely on a theoretical framework based on both the evolutionary and ‘systems’ approaches towards innovation to understand how firms’ knowledge accumulation and innovation strategy changed over time. This is operationalized through the construct of two case studies based on firms’ patents, historical records, and broader industrial context. Our analysis is centered around industrial robots – generally regarded as intermediate products against the broader framework of user-producer interaction. While service robots are increasingly important (as later sections would demonstrate), the paper is more concerned with industrial robots that still comprises much of the industry. As such, the core of the discussion is devoted to this sub-sector.

The study adds to the growing literature that uses patent data in understanding firm’s innovative behavior (among others, Stuart & Podolny, 1996; Rosenkopf & Nerkar, 2001; Katila & Ahuja, 2002; Ahuja & Katila, 2004). Our novel contribution is the development of an integrated
framework, that combines a variety of objective patent-based analytical measures with rich case studies based on historical archives, that provides the reader with a holistic and detailed study of the evolution of the firms’ innovative strategies over time.

The remainder of the paper is structured as follows. Section 2 provides a brief theoretical review of firms’ accumulation of technological knowledge. Section 3 depicts the contemporary robotics landscape. Section 4 discusses the hypothesis and the methodology that the analysis follows. Section 5 delves into the case studies of the selected firms. Section 6 provides a brief discussion and concludes.

II. Literature review: accumulation of technological knowledge and innovation strategies

In adopting an evolutionary approach, we view the enterprise as a behaviorally-constrained entity that routinely seeks competitive advantage. It relies on established routines to reduce its internal tensions and to allow it to navigate its unfolding and uncertain market environment (Nelson & Winter, 1982). Firms root these routines in their existing technical knowledge base and are likely to select new combinations that approximate that base, allowing organization to accumulate a particular set of related capabilities (Dosi, 1988; Dosi, Nelson & Winter, 2001) towards a particular irreversible direction (Nishimura & Ozaki, 2017).

This means that the firm’s operating environment is populated with other organizations that feature their own behavioral specificities. However, in time, a technological paradigm likely emerges that limits the amount of existing variety and sets the best practices for organizations to conduct their business (Dosi, 1988). The paradigm defines the particular direction by which the industry grows (and which firms survive and exit) and discovers innovative opportunities (Nelson & Winter, 1973; Nelson & Winter, 1982; Dosi & Orsenigo, 1988).

Sectoral system approaches have highlighted latent feedback mechanisms and learning processes among the stakeholders in carrying out innovative work. Internal-based learning dynamics ‘learning-by-doing’ (Arrow, 1962), ‘learning-by-using’ dynamic (Rosenberg, 1982) and Lundvall’s (1985) ‘learning-by-interacting’ process is grounded by costs for the firm, particularly with regard to the ‘stickiness’ of the available information in the environment (von Hippel, 1994). Compatible with the broader evolutionary thought, these mechanisms serve to reinforce (or weaken) the existing structures for the realization of the system’s overall stability (or dissolution) (Fagerberg, 2003). Both the established routines and underlying learning processes determine how the firm responds to the various emergent innovations, which may either arrive as continuous improvements to existing goods (or ‘incremental’ innovations) or as revolutionary changes that overhauls existing productions processes (or ‘radical’ innovations) (Fagerberg, 2003). Early Schumpeterian thought was particularly predisposed towards radical innovations, but more recent discourses have progressively placed importance to incremental innovations and invention (Rosenberg, 1976; Lundvall, 2016).

Regardless of the innovation being introduced, the broad literature has increasingly recognized the value of maintaining diverse technological capabilities for firms to respond to such stimuli properly. Investigations in the evolutionary tradition have long held the view that innovating organizations maintain position in a diverse set of technologies (Dosi, 1982; Nelson & Winter, 1982). Successful firms build their comparative advantage through their organizational
competence in combining large sets of technological competencies (Pavitt, 1991) or incorporating new technologies into existing processes (Quintana-Garcia & Benavides-Velasco, 2008).

Through these various dimensions, the overall body of literature to better delineate sectors on the basis of technological and industrial characteristics (Fagerberg, 2003). Prominent examples of such attempts include Pavitt’s (1984) external sources-focused taxonomy. The availability of these classifications allowed for a more nuanced differentiation of various ‘high-technology’ industries. For example, it became possible to better distinguish the dynamics in the electronics industry with that in durable consumer goods (i.e. automotive).

Of particular relevance to the understanding of innovative dynamics in industries similar to robotics, is the observation that the interactions between producers and external sources were valuable in directing the innovative process. For instance, in the manufacture of electronic sub-assembly process equipment, Von Hippel (1977) noted that there were several cases wherein the innovative work is a collaborative work between the manufacturer and the user. The literature also underscored the importance of maintaining a diversified knowledge base in such industries, as demonstrated in Brusoni, Prencipe, and Pavitt’s (2001) investigation of multi-technology product manufacturers. Following Pavitt’s (1984) taxonomy, the literature has identified these organizations as ‘specialized suppliers’ who build their competitive advantage in having a thorough understanding of users’ needs. Moreover, Pavitt (1984) added that these manufacturers often innovate with a bias towards performance improvements, such as in product design and reliability.

Drawing parallels once more with the evolutionary approach, the noted studies remarked that most user-producer interactions also serve to stabilize the direction of technological development. As user-producer relationships deepen, the orientation of innovative output is increasingly centered on a limited set of identifiable problems that the market demands to be addressed (Rosenberg, 1976; Klevorick, Levin, Nelson, & Winter, 1995); a ‘natural trajectory’ consequently emerges (Nelson & Winter, 1982). As such, the broad industry runs the risk of being locked-in into a specific path through various self-reinforcing effects (Fagerberg, 2003). As the relationship and dynamics become more stable, the environment may foster ‘dynamic inertia’ that implies an indifference towards new technical opportunities and user needs (Lundvall, 1985).

III. Research setting: the contemporary robotics industry

The International Organization for Standardization (ISO) and the United Nations Economic Commission for Europe (UNECE), through the ISO-Standard 8373 of 2012, loosely defines a robot as a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response.

Robots promise cost-efficiency and greater accuracy and reliability relative to human agents (ABB Group, 2016; PwC, 2017). They are able to perform tasks that are highly dangerous (i.e. nuclear power plants’ decontamination), repetitive, stressful, labor-intensive (i.e. welding), or menial for human agents. The IFR and the industry at large currently adheres to two classifications of robots: industrial robots (IR) and service robots (SR). An industrial robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications (ISO 8373, 2012). A
service robot is a robot that performs useful tasks for humans or equipment excluding industrial automation applications (ISO 8373, 2012).

Various but related developments in hardware and software technologies, academic research, and in the industry itself in recent years have enabled the sustained expansion of nascent sub-sectors, particularly those related to the digitization of production. Most prominent among these next-generation robots are the interactive robots, as these are expected to be viable in environments wherein various forms of interactions with human agents take place, and are intuitive, easy-to-use, and responsive to user needs (Christensen et al., 2016). Among them, the most anticipated subclass are the collaborative robots or co-bots. They were invented by Northwestern University McCormick School of Engineering professor Edward Colgate (with Michael Peshkin), and are mechanical devices that provide guidance through the use of servomotors while a human operator provides motive power (Krüger et al., 2009; Morris, 2016). In practice, the distinguishing feature of a co-bot is its ability to provide direct power support to a human agent in a strenuous task while maintaining a high level of mobility (Lau, 2005). While co-bots are employed mostly in manufacturing tasks, they are also viable for non-traditional applications such as surgery (Delnondedieu & Troccaz, 1995).

III.A. A brief account of the evolution of the robotics industry

Roboticists date the birth of the contemporary robotics landscape to around the mid-1950s to the 1960s, when Joseph Engelberger, of Consolidated Controls, together with inventor Joseph Devol, launched the Unimate robot as a novel approach towards automating production (Robotics Industry Association, 2018). Through Engelberger’s efforts, the Unimate robot was commercially applied in a General Motors assembly line in Trenton, NJ by 1961. Two years after, around 450 of such machines were employed in die casting activities across the carmakers’ plant (Robotics Industry Association, 2018). However, the adoption of the technology was slow and Engelberger (1985) acknowledge that his company did not profits until 1975 because potential clients found it difficult to find economic justification for robots’ installation (despite a clear value proposition and popular support) at the time. It was not until strong labor unions and increased militancy among workers in the US (Greenhouse, 1998) and Europe ca. 1970s (Tagliabue, 1982) that introduced innovative employee benefits (such as employer-financed pensions and cost of living adjustments), that car companies increasingly considered the adoption of more automated modes of production.

At the time of Unimation’s first commercialization, much of the research efforts were carried out in various university research laboratories such as Stanford, Massachusetts Institute of Technology (MIT), and the Carnegie Melon University (CMU) (Kurfess, 2005). As Kurfess (2005) pointed out, most of these activities sought to improve machine intelligence and enable robots to respond in unstructured settings. Most prominent among these endeavors was that of Stanford student Victor Scheiman’s Stanford arm in 1969, the first six-axis robot that demonstrated assembling capabilities thereby expanding potential robot applications (Corday, 2014).

The succeeding decade witness the geographical spread of robotics from beyond American soil, as Engelberger introduced robotics to partners in Scandinavia and Eastern Europe (through Nokia of Finland) and Japan (through Kawasaki Heavy Industries) (Robotics Industry Association, 2018). Engelberger (1985) pointed out that the Japanese firms may be regarded as the catalyst towards a broader adoption of robotics use in manufacturing. He noted that Japanese companies
have been enthusiastic in exploring the potential of the technology and have eagerly applied the machine in their assembly lines. Comparable developments in the use of robotics in industrial applications were also being carried out throughout Western Europe, albeit by different organizations (the companies of interest in the study).

Material handling was the main application area for robotics in the 1970s and the 1980s (Wallén, 2008). In addition, Wallén (2008) noted that arc welding and assembly activities were emerging areas of application at the time, but both activities required better motor and control systems in the machines. Regarding the main user industries, Wallén (2008) observed that the automotive industry was the most valuable client ca. 1970s, with the metal sector as another group of significant users.

Despite the steady growth, employment of robots remained limited because of substantial costs and of inherent limitations in ‘hard automation’ technologies that require 24/7 operations (Ayres & Miller, 1981). Particularly in 1970s and 1980s US manufacturing remained predominantly done in batches, which means that production only runs for extended hours or days. Prospective clients, who are those in batch-producing industries, had concerns regarding the likely underutilization of the machines in the shop floor because any cost savings were mitigated by under-capacity issues (Carter, 1985).

The 1980s and the 1990s saw the steady expansion of robotics’ use in various industries, although the automotive industry remained the most significant user – with General Motors (GM) as the leading robotics purchaser at the firm level (Miller, 1989). The other major industries that used robots included home appliances, consumer goods, electronics, and off-road vehicles. Miller (1989) noted that there was substantial interest from the aerospace sector at the time, but most of the robotics projects were only exploratory. By the late 1980s, there were industrial producers in Germany, Italy, Japan, and Sweden (Porter, 2011).

Press releases from the United Nations Economic Commission for Europe and the International Federation of Robotics (1996, 1999) suggest that the decade saw a relatively uneven growth for the industry. Global sales of robots receded from 1991 to 1993, succeeded by a recovery until 1997, and followed by a decline by 1998. Major markets like the US, Europe, and East Asia saw notable fluctuations in demand across the years, due to the economic crises during the decade. Throughout, automotive industry continued to be the largest customer. Other significant sectors of robot applications at the time included off-road vehicles, electronics, food, pharmaceuticals, appliances, aerospace, and metal fabrication (UN – IFR, 1996). Of note, the latter half of the 1990s saw the exploratory activities related to the transformation of IRs for service applications. Industry analysts attribute the viability of SRs primarily to the falling costs and increasing capabilities of the machines (UN – IFR, 1999).

Based on IFR operational stock data for the period 1993 to 2015, Table 1 shows that demand distribution remained heavily concentrated, particularly in the four industries of automotive (38%), electrical/electronics (24%), metalworking (13%), and plastic and chemicals (13%). The fifth-largest, the catch-all category for all other manufacturing activities, only has an average share of around 6% throughout the specified time frame. Demand has not substantially picked up in other industries.
As expected, the automotive sector is the largest demand source for robots. In the period 1993 to 2000, the industry had an average share of around 30%; since then, carmakers have maintained an average share between 40 to 45%. In contrast to the growth among carmakers, the electronics industry (the other major market for robots) witnessed a boom in demand during the 1990s (with an average of 30%) that levelled by the start of the 21st century (with an average of around 21%). Year-on-year analysis of the operational stock data (see Table 2) supports these increasing trends. Furthermore, it also suggests that there is steady annual growth in other industrial applications such as food and beverages (wherein both overall YOY and by-decade YOY calculations are indicative of increasing adoption). However, the broader trend seemingly intimates at the persisting challenge of applying robots to non-traditional applications. Outside of food and beverage, all other sectors except for the identified-4 have posted a negative average throughout the time frame. Positive YOY averages for the non-traditional applications were only noted from 1993 to 2000.

Focusing on the IFR delivered robots (robot sales) during the same period (see Table 3), the statistics demonstrate the increasing adoption of robotics in industrial applications. In 1993, robots for manufacturing use had an 18% share of total robot sales while robots for unspecified use (outside of traditional agricultural and service applications) had an 82% share. By 2015, robots for manufacturing had a 91% share and robots in unspecified applications were at 8% share. Furthermore, the data also provides evidence of the drastic drop in robot demand post-crisis: there were noticeable demand decreases in years 1998 and 2009, which were right after the 1997 Asian financial crisis and the 2008 financial crisis.

### Table 1. World robotics operational stock 1993 – 2015 share averages, by manufacturing sub-sector

<table>
<thead>
<tr>
<th>Industry</th>
<th>Total Ave</th>
<th>SD</th>
<th>93 - '00 Ave</th>
<th>SD</th>
<th>01 - '10 Ave</th>
<th>SD</th>
<th>11 - '15 Ave</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food and beverages</td>
<td>2.15</td>
<td>1.01</td>
<td>1.13</td>
<td>0.12</td>
<td>2.13</td>
<td>0.58</td>
<td>3.52</td>
<td>0.18</td>
</tr>
<tr>
<td>Textiles</td>
<td>0.20</td>
<td>0.08</td>
<td>0.29</td>
<td>0.01</td>
<td>0.18</td>
<td>0.05</td>
<td>0.11</td>
<td>0.01</td>
</tr>
<tr>
<td>Wood and furniture</td>
<td>1.13</td>
<td>1.23</td>
<td>2.21</td>
<td>1.69</td>
<td>0.76</td>
<td>0.16</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>Paper</td>
<td>0.33</td>
<td>0.05</td>
<td>0.34</td>
<td>0.03</td>
<td>0.36</td>
<td>0.03</td>
<td>0.28</td>
<td>0.03</td>
</tr>
<tr>
<td>Plastic and chemicals</td>
<td>12.67</td>
<td>1.08</td>
<td>12.69</td>
<td>0.69</td>
<td>13.46</td>
<td>0.56</td>
<td>11.52</td>
<td>0.67</td>
</tr>
<tr>
<td>Glass, ceramics, minerals</td>
<td>0.81</td>
<td>0.12</td>
<td>0.82</td>
<td>0.19</td>
<td>0.85</td>
<td>0.02</td>
<td>0.73</td>
<td>0.06</td>
</tr>
<tr>
<td>Metal</td>
<td>13.07</td>
<td>2.06</td>
<td>15.55</td>
<td>1.57</td>
<td>12.10</td>
<td>0.69</td>
<td>11.35</td>
<td>0.19</td>
</tr>
<tr>
<td>Electronics</td>
<td>23.92</td>
<td>4.69</td>
<td>29.73</td>
<td>1.81</td>
<td>20.03</td>
<td>1.95</td>
<td>22.03</td>
<td>1.17</td>
</tr>
<tr>
<td>Automotive</td>
<td>38.35</td>
<td>7.36</td>
<td>29.13</td>
<td>1.37</td>
<td>41.71</td>
<td>4.30</td>
<td>45.41</td>
<td>0.41</td>
</tr>
<tr>
<td>Other vehicles</td>
<td>1.47</td>
<td>0.87</td>
<td>2.48</td>
<td>0.36</td>
<td>1.21</td>
<td>0.55</td>
<td>0.57</td>
<td>0.01</td>
</tr>
<tr>
<td>Others</td>
<td>5.91</td>
<td>2.52</td>
<td>5.63</td>
<td>3.22</td>
<td>7.22</td>
<td>2.00</td>
<td>4.17</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Source: IFR (2018)

### Table 2. World robotics delivered robots 1993 – 2015, by select years in select industries

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>9,564</td>
<td>14,706</td>
<td>60,638</td>
<td>53,843</td>
<td>74,860</td>
<td>101,000</td>
<td>94,213</td>
<td>49,162</td>
<td>99,268</td>
<td>231,502</td>
<td></td>
</tr>
<tr>
<td>Unspecified applications</td>
<td>43,724</td>
<td>54,507</td>
<td>19,873</td>
<td>14,331</td>
<td>23,184</td>
<td>18,542</td>
<td>18,158</td>
<td>9,938</td>
<td>20,088</td>
<td>20,007</td>
<td></td>
</tr>
<tr>
<td>All Industries</td>
<td>53,409</td>
<td>69,260</td>
<td>81,675</td>
<td>69,025</td>
<td>98,667</td>
<td>120,100</td>
<td>112,972</td>
<td>60,018</td>
<td>120,585</td>
<td>253,748</td>
<td></td>
</tr>
</tbody>
</table>

Source: IFR (2018)

Recent developments in big data, data storage, computational capacity and algorithms, having accelerated the developments in artificial intelligence, promise to radically alter the sector dynamics throughout its history. The second part of the 2010s has witnessed not only daily
announcements of new futuristic fully interactive robots by technological startups, but also the successful development of interactive robots (particularly, co-bots) that have been introduced in manufacturing allowing more extensive human-robot collaboration that could open the way to new productivity increase in the factory (Shah et al., 2011). Gains have already been realized in a number of early adopters, who are mostly car manufacturers (Nisen, 2014; Luxton, 2016; Zalecki, 2016). These next-generation robots are expected to be a significant driver of industry growth in the coming years (Lawton, 2016; Universal Robots, 2016) though that will happen only if their diffusion will be parallel by a radical rethink of the organization of the factory.

IV. Methodology

In this investigation, a qualitative case study approach is employed to understand the development of innovation strategies in the focus firms. Following the general prescriptions of Yin (2003), the cases were constructed through gathered data first from patents, then from company reports, and news archives.

The study’s reliance of patent data stems from a long tradition in innovation studies, such as in determining inter- and intra-industry differences in innovation behavior (Scherer, 1965, Achilladelis, Schwarzkopf, & Cines, 1990), in understanding knowledge spillovers (Jaffe, Trajtenberg, & Henderson, 1993) across time (Jaffe, 1996, 1998) and regions (Maurseth, Verspagen, 2002). Despite concerns regarding the information in patents and their use, patents figure in economic research because it provides a ‘better’ alternative than traditional measures in understanding inventive activity in the economy (Griliches, 1998). In particular, the research builds on a nascent sub-set of studies that rely on patent data to understand firms and their individual innovative strategies. Operationally, this means that we interpret patent data as signals and traces of the firm’s knowledge base and technological competencies. We think that in doing so, our investigation is less impeded by the known limitations in patent-based research.

We characterize firms’ innovative behavior on the bases of: 1) technological diversity and competencies and 2) search tendencies. Technological diversity and competencies are measured through a diversification measure and Revealed Technology Advantage (RTA) estimations. Search tendencies are a comparative analysis of the firms’ external and internal searches. Table 3 lists these measures and their calculations.

The combination of these patent-based results is expected to allow the research to properly identify the milestone narratives that would reduce researcher bias in the studies’ constructs. In detail, we expect the anticipated trends and breaks in the firms’ overall innovation strategies over time would serve as our primary guideposts that would allow us to deduce the relevant data to be gathered from company reports, news archives, and financial databases. Overall, we expect that the

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1 See Griliches (1998) for a summary of patent-related issues. More recent critiques on patents are made in Duguet & MacGarvie (2005) (regarding patents’ inability to characterize the learning process through imitation and reserve engineering) and in Roach & Cohen (2013) (regarding patents’ importance in firms’ strategic behavior). There are also concerns regarding the patent application process itself, see Alcacer & Gittelman (2006) on examiner bias and Jaffe, Trajtenberg, & Fogarty (2000) on patents as ‘noisy’ measure of knowledge spillovers.

combinations of all these various data points would not only expand the existing chains of evidence but also reinforce our logic assumptions in the studies.
Table 3. Summary of patent data-based measures used in the research

<table>
<thead>
<tr>
<th>Name of measure</th>
<th>Source</th>
<th>Formula</th>
<th>Variables</th>
<th>Patent data used</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological diversification index</td>
<td>Quintana-Garcia &amp; Benavides-Velasco (2007)</td>
<td>(1 - HHI = 1 - \sum p_i^2)</td>
<td>(p_i) is ratio of patents in technical field (i)</td>
<td>4-level IPC subclass</td>
<td>Derived from the Herfindahl-Hirschman Index, it is equal to zero when a firm does research only in a singular technology and approximates unity when the enterprise spreads its research activities over a wide technological base. Patents assigned to multiple technical fields have been treated as different applications.</td>
</tr>
<tr>
<td>Technological profiles</td>
<td>Patel &amp; Pavitt (1997)</td>
<td>(TP = \frac{PS}{RTA})</td>
<td>(PS) is IPC subclass share in the firm’s total IPC subclasses in a stock-year</td>
<td>4-level IPC subclass</td>
<td>IPC subclasses are classified as either core, niche, background, or marginal competencies that are defined as follows: core as the firm’s distinctive technical competencies, niche as those that are distinctive but are relatively small technological fields, background that are competencies wherein the firm allots significant resources but is unable to achieve a relatively high advantage because of the field’s size, and marginal in which the firm neither allocates sizeable resources nor achieves distinct advantages (Patel &amp; Pavitt, 1997)</td>
</tr>
<tr>
<td>Revealed Technological Advantage</td>
<td></td>
<td>(RTA_{ij} = \frac{P_{ij} / \sum P_{ij}}{\sum P_{ij} / \sum P_i})</td>
<td>(P_{ij}) is the number of patents of firm (i) that belongs to IPC class (j) applied with the EPO</td>
<td>4-level IPC subclass</td>
<td>Because of data constraints, we had to rely on the OECD data on all patent applications to the EPO from 1987 to 2014. It must be noted that the OECD statistics are fractional counts(^4) of the entire EPO applications.</td>
</tr>
<tr>
<td>Local-distant knowledge search index</td>
<td>Rosenkopf &amp; Nerkar (2001); Katila &amp; Ahuja (2002)</td>
<td>(\text{Scope}<em>{it} = \frac{n</em>{cit}}{t_{cit}}) (\text{Scit}) is citations made in firm (ss_t) but not in firm (ss_{t-1}); (t_{cit}) is self-citations</td>
<td>Patent citations</td>
<td>Firm citation stock was calculated as:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(\text{SC}<em>{it} = \frac{s</em>{cit}}{t_{cit}})</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\(^3\) See Appendix A for a more extensive documentation of the methodology.  
\(^4\) The OECD uses the fractional count approach to disentangle patent applications made by inventors with different nationalities; disentangling the patent’s ‘nationality’ allows the OECD to better approximate the countries’ patent contributions. Although it is likely to differ from a straight count of the EPO data, the effect is likely not to effect our research as the analytical focus is on understanding the evolution of firm capabilities over time and not the absolute RTA values.
Each index value was determined using a composite *stock-year*, aggregated from available data at the individual year level such that each *stock year* is the total stock of knowledge for the past five years. For instance, *stock-year* 1991 means that 1991 is the sum for the period 1987 to 1991. This approach allows to reduce the statistical noise and also to operationalize the following: 1) the cumulativeness of organizational knowledge; 2) the depreciation of knowledge (Argote, 2013); and 3) the bias towards recent knowledge of both organizational and individual memory (Alcacer & Gittleman, 2006). According to Katila & Ahuja (2002), other configurations of yearly aggregation do not yield significantly different results. A *stock-year* is constructed for each year from 1991 to 2015.

Regarding the cases’ focus, we concentrate on Europe for three main reasons: 1) the presence of both industry-recognized robotics companies and of dynamic national markets (whereas, top Asian robotics producers are mostly concentrated in Japan and some of Asia’s largest markets (i.e. China, South Korea) have no sector-recognized top robotics producers yet), 2) the availability of comparable cross-country patent data at the European Patent Office (EPO), and 3) the limited language constraints. A similar selection criteria were employed in choosing the firms for the case studies, in that they must be industry-recognized ‘top firms’ and are headquartered in the largest European markets. Considering that the two largest robotics demand bases in Europe are in Germany and in Italy (Estolatan et al. 2018), the research focuses on German robotics producer KUKA AG and Italian COMAU SpA.

The selected sample of patents for analysis are the firms’ patents applied with the EPO from 1987 to 2015. The data is primarily obtained through Clarivate Analytics’ Derwent Innovation database, corroborated with comparable data drawn from Bureau van Dijk’s (BvD) Amadeus database. Furthermore, constructed M&A histories from company reports and news archives are employed to validate gathered patent data. This yielded a total patent count of 355 for COMAU and 1,132 for KUKA. We extracted the bibliometric information commonly used in the literature: number of IPC subclasses, both application and publication years, patent citations, and the cited patents’ first assignees.

Firms’ financial and subsidiaries information are obtained from the Amadeus database. Supplemental company information and M&A-related data are gathered from the Amadeus database, firms’ annual reports, and news articles.

As a final note, we recognized that the 355-patent count for COMAU is low and may, thus, underrepresent the total knowledge base of the company. As our case study for the firm expounds, this likely stems from COMAU’s role as a subsidiary of the larger Fiat Chrysler Automobiles (FCA) Group that had centralized its R&D outputs in designated laboratories. Nevertheless, we think that this investigation is worth pursuing with the gathered sample because it still represents the core technological knowledge of COMAU.

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5 Particular on the data, relying exclusively on those available at the EPO allows for consistency, reliability, and comparability across the firms (Griliches, 1998). Furthermore, the literature has noted the stability of EPO data over time and across countries (van Zeebroeck, van Pottelsbergh, & van Pottelsberge de la Potterie, 2006). Last, while patent citations are susceptible to examiners’ influence during the application process, previous investigations noted how European examiners are more stringent in their addition relative to their American contemporaries (Alcacer & Gittleman, 2006).

6 While there are other more prominent and larger producers in Europe than COMAU, they are either headquartered in countries without a robust demand (i.e. Swiss firm Stäubli Holding AG) or are significantly involved in other lines of businesses (i.e. Swiss/Swedish ABB Group and its exposure to electrical systems production).
V. The accumulation of technological knowledge: the cases of COMAU SpA and KUKA AG

V.A. COMAU SpA

COMAU, a name derived from the acronyms of CONsortio MAchine Utensili (consortium of machine tools), was established back in 1973 by Torino-based engineers who helped in building the Russian Volga Automobile plant. A FIAT subsidiary since its inception, it mainly worked in industrial automation and advanced manufacturing systems. COMAU was instrumental in helping FIAT transform its manufacturing sites into automated factories through the development and introduction of its highly-flexible Robogate systems (Camuffo & Volpato, 1996). In the 1980s, COMAU leveraged this expertise to enter the North American market (through its affiliate Comau Productivity Systems) and to work with German mechanical engineering TRUMPF Group in developing laser robots. From the 1990s until the turn of the century, COMAU expanded beyond servicing FIAT’s plants and its North American partners (mainly, General Motors at the time) and steadily established presence in other European countries, South America, and Asia. Furthermore, the firm started developing automation solutions and equipment maintenance services for related industries, such as aerospace, heavy vehicles, railways, and renewable engines. During that time, some of COMAU’s notable acquisitions included Renault Automation France, germanINTEC GmbH, and North American bodywork systems manufacturer Progressive Tool and Industries Co. (PICO). At the beginning of the 21st century, COMAU was a high-technology enterprise that offered an integrated value proposition (from automation solutions to aftermarket maintenance) to its customers.

Company documents suggest that COMAU was confronted with significant headwinds in the 2000s. As early as 2004, the firm had gone through some minor restructuring activities that saw its Mirafiori capabilities (i.e. service and die) be transferred to parent FIAT Auto and FIAT-GM power train and a significant part of its total servicing and maintenance operations distributed to sister companies like IVECO, Magneti Marelli, and CNH. By third-quarter 2006, the FIAT Group entered COMAU into a significant restructuring program by third-quarter 2006. Taking approximately 2 years, it led to down-sizing and several divestments (particularly, the sales of COMAU France’s engineering business, COMAU’s South African businesses, and COMAU subsidiary germanINTEC, and the transfer of Turin’s engineering division to affiliate Elasis Group). Alongside that, FIAT consolidated its research efforts into two non-COMAU subsidiaries: 1) Centro Ricerche FIAT (Piemonte) and 2) Elasis (Southern Italy) in 2007. When FIAT and Chrysler merged into the FIAT Chrysler Automobiles (FCA) Group in 2008, COMAU increased its exposure to the Group’s companies. It became responsible for modernizing the Group’s (particularly, those of Chrysler’s) operations. A significant portion (around 25 – 30%) of COMAU’s sales has been made to the Group’s companies throughout the years. COMAU today is mainly involved in powertrain metal cutting systems, mechanical assembly systems and testing, innovative and high-performance body welding and assembly systems and robotics.

Most recent financial statistics (albeit limited7) from 2008 to 2015 (see Table 3) exhibit the firm overhaul. The first half of the seven-year period was characterized with negative net income. It was only in 2012 that COMAU had started to reap the benefits of its strategy, as it began realizing

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7 A more detailed financial data is available for COMAU’s operations in Italy during the same period. See Appendix B for reference.
profitability. Employee count in the first half of the period was around 12,000 employees on average; COMAU only had around 9,000 employees spread in 17 different countries by 2018.

Table 4. COMAU SpA financial highlights 2008 - 2015, in thousands EUR

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current assets</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total assets (TA)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Non-current liabilities</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Current liabilities</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Total liabilities (TL)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Operating revenue</td>
<td>1,123,000</td>
<td>728,000</td>
<td>1,023,000</td>
<td>1,402,000</td>
<td>1,482,000</td>
<td>1,463,000</td>
<td>1,550,000</td>
<td>1,952,000</td>
<td>1,340,375</td>
</tr>
<tr>
<td>Period P/L (Net income) / EBIT</td>
<td>NA</td>
<td>(32,000)</td>
<td>(6,000)</td>
<td>(120,000)</td>
<td>33,000</td>
<td>47,000</td>
<td>60,000*</td>
<td>72,000*</td>
<td>(15,600)</td>
</tr>
<tr>
<td>No. of employees</td>
<td>11,445</td>
<td>11,708</td>
<td>12,216</td>
<td>14,457</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>~9,000**</td>
<td>NA</td>
</tr>
<tr>
<td>Current (working capital) ratio</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>TL/TA ratio</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Source: Amadeus database (2018)

Notes: R&D expenses includes capitalized R&D and R&D charged directly to income statement.
*EBIT Report was adjusted in 2013 to reflect subsidiary’s adjusted EBIT.
**Estimated employees’ number from recent annual reports

COMAU’s combination of patent-based measures are aligned with the above developments. Our analysis suggests the following: a) the enterprise sustained high technological diversification from 1991 to 2015, b) a marked reduction and shift in its technology mix around the mid-2000s, and c) a behavioral shift in its local knowledge vs. distant knowledge search around the mid-2000s.
Figure 1. COMAU SpA and KUKA AG diversification measures, stock-years 1991 – 2015

Figure 2: COMAU SpA Technology Profiles 1991 / 2014 (IPC and NACE economic activity)

<table>
<thead>
<tr>
<th>Background</th>
<th>Stock-year 1991</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IPC Subclass</strong></td>
<td><strong>Economic activity</strong></td>
<td><strong>IPC Subclass</strong></td>
</tr>
<tr>
<td>G05B</td>
<td>instruments and appliances for measuring</td>
<td>B23K</td>
</tr>
<tr>
<td>B21D, B23Q</td>
<td>metal forming machinery &amp; machine tools; machinery &amp; equipment</td>
<td>B25J</td>
</tr>
<tr>
<td>G01B</td>
<td>computer, electronic, and optical products</td>
<td>B62D</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Marginal</th>
<th><strong>IPC Subclass</strong></th>
<th><strong>Economic activity</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IPC Subclass</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B30B</td>
<td>fabricated metal products, except machinery</td>
<td></td>
</tr>
<tr>
<td>G01D</td>
<td>instruments and appliances for measuring</td>
<td></td>
</tr>
<tr>
<td>B60J</td>
<td>motor vehicles</td>
<td></td>
</tr>
<tr>
<td>C09J</td>
<td>other chemical products</td>
<td></td>
</tr>
<tr>
<td>B65G</td>
<td>other general purpose machinery</td>
<td></td>
</tr>
<tr>
<td>H02G</td>
<td>wiring and wiring devices</td>
<td></td>
</tr>
<tr>
<td>E04H</td>
<td>specialized construction activities</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Niche</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic activity</strong></td>
</tr>
</tbody>
</table>


COMAU’s select technological profiles from 1991 to 2015 augment these observations (see Figure 2). On average, among the firm’s 73% of classifiable technologies in the Patel-Pavitt matrix, 28% are identifiable as core technologies, 7% as niche, 14% as background, and 25% as marginal. Particular on the noted ‘technology mix’ shift, there were substantial reductions in marginal and background technologies and a notable consistency in core capabilities. Apart from these, there is an observable capacity-building in computing and electronics manufacture, particularly in measuring instruments – from being a background competency, it has evolved into a core competency by the 2014 profile.

Regarding the local-distant knowledge search contrast (see Figure 3), COMAU’s behavior over 25 years are marked by notable shifts and limited trends. The overall search propensity is relatively consistent, with roughly a quarter of new knowledge is added to the total knowledge base on
average. Interestingly, there was a marked shift around the mid-2000s when COMAU substantially increased its self-citation intensity; self-citation behavior began to decrease by 2011.

V.B. KUKA AG

KUKA started when Johann Josef Keller and Jakob Knappich founded "Acetylenwerk für Beleuchtungen in Augsburg" back in 1898. KUKA emerged from the founders’ oft-used abbreviation in their telegrams – the first letters of “Keller und Knappich Augsburg.” The 120-year old company began with providing illumination for Augsburg households and streets but soon ventured into welding-related activities. It since focused in welding technologies and related activities, such as cutting processes. It then leveraged these competencies towards industrial-scale production, particularly for municipal vehicles and consumer appliances manufacturing. In doing so, KUKA was able to develop capabilities in industrial automation.

Industrial automation capabilities have increasingly become part of KUKA’s core offerings that when the company merged with Industrie-Werke Karlsruhe AG in the early-1970s to form IWKA AG, these competencies have been the ones mainly carried over. Apart from those, the new enterprise had exposure in the areas of packaging machinery, textile engineering, control technology, metal forming, and machine tools. By the 1980s, KUKA (now IWKA) has transformed itself into holding company for various (but loosely) interrelated businesses focused on environmental, welding, and defense technologies. The succeeding years saw KUKA continue to develop its competencies and market expansion (particularly, in North America). Most notable during that period was KUKA’s acquisitions of the German technology enterprise Rheinmetal Group and the Anglo-American BWI Group in 1999; these strengthened the enterprise’s packaging activities. At the start of the 21st century, KUKA was a broad-based technology group that primarily dealt with production (welding), manufacturing (automation), process (controls and measurement), and packaging technologies for an extensive set of industries.

KUKA steadily invested in robotics-related technologies over the years. KUKA was responsible for the installation of robotic welding transfer lines in Daimler-Benz’s plants back in 1971. In 1973, KUKA (now IWKA) introduced FAMULUS, which the company claims were the first industrial robot with six electromechanically driven axes. In the 1990s, KUKA began introducing open-source controlling mechanisms for its automated machines. Throughout the abovementioned period, robotics remained important to the enterprise’s development.

KUKA’s Annual Reports indicate that operational risks and an unfavorable economic environment pressured the company to restructure in the mid-2000s. As early as 2000, KUKA started selling its defense-related technologies. By 2004, it has entered into an expansive divestment process that saw its non-core businesses and process technologies sold. For the next three years after 2004, KUKA continued to make divestments. Some of the notable sales in those years included the severance with machining providers EX-CELL-O Group and the Boehringer Group and standard machine tools producer GSN Maschinen-Anlagen-Service GmbH (KUKA AG, 2006). Furthermore, KUKA completed its 2004 targets when it discontinued ties with the Bopp & Reuther-affiliated VAG-Armaturen GmbH (KUKA AG, 2004) and the RMG group (natural gas distribution measurement activities) (KUKA AG, 2005). In 2007, KUKA sold off all the companies primarily involved in its packaging technologies (KUKA AG, 2007). KUKA employment shrank from just about 12,000 in 1999 to just above 5,000 in 2007. However, the period also saw KUKA refocus from a broad-based enterprise into a robotics and production
systems specialist. When it re-established itself as KUKA AG, the company had only two business segments: robotics and automation systems. This delineation of operations had remained stable until 2013. Robotics became a central component in KUKA’s business strategy after (and even during\(^8\)) the restructuring phase. The company intended to deepen and leverage its robotics expertise to a more diverse set of non-automotive industries, that includes plastics processing, logistics, and medical technologies, and food and processing sectors. The change of executive management in 2009 accelerated these goals and resulted in a more aggressive marketing of robotics to potential non-automotive applications (McGee, 2017). Some notable post-restructuring robotics-focused milestones included the establishment of the Advanced Robotics section (KUKA laboratories) within the Robotics division and the foray into collaborative robots through the lightweight robot (LWR) development back in 2011. Regarding its mergers & acquisitions, KUKA embarked on a broad M&A strategy to strengthen its core divisions. Some of its acquisitions (all completed in 2014) included the following: Reis Group, which expands KUKA Systems Division’s capabilities in the cell business for general sectors; Alema Automation SAS, which gives KUKA Systems competencies in providing industrial automation for aircraft manufacture; a stake in FAUDE Automatisierungstechnik GmbH, a production and process automation provider that specializes in human-robot collaboration. Most notable among all its M&A activity was KUKA’s 2014 merger with Swisslog Holding AG, a century-old Swiss robotics company that specializes in automation solutions for warehouse logistics (particularly in the demand segments of e-commerce, pharmaceuticals, and temperature-controlled foodstuffs) and the healthcare sectors. KUKA integrated Swisslog as a subsidiary and completed the process in 2015. Latest management discussion reiterated KUKA’s ambition to leverage its robotics and industrial automation know-how into a variety of industries, that include automotive, aerospace, electronics, FMCG, metals, energy, healthcare, and e-commerce industries. Revisiting KUKA’s patent-based technological profiles in the latter years exhibit this increase in scope of the firm’s knowledge base and diversification towards potential new robotics users’ industries (with different technological characteristics and requirements), such as warehouse automation and healthcare.

Financial data from 2008 to 2015 (see Table 4) exhibit small but discernible traces of the restructuring process that KUKA underwent (much of which happen in the years just before). The statistics also demonstrate the periods of relative stability and the succeeding abrupt change in pace that KUKA went through when it changed executive management in 2009. Years 2008 and 2009 (and to a lesser extent, 2010) suggest that there was a contraction across the board (reductions in R&D expenses and employee counts persisted until 2010). Thereafter, organizational growth remained relatively tame; KUKA focused on reducing its losses and leverage and improving its liquidity. Effects of the management change started to materialize in the books around 2013, as KUKA significantly increased its current assets, current liabilities, and R&D expenses and posted flat growth in profitability. Sizeable increases across all metrics became notable in the years after that, although KUKA saw its highly liquidity and low leveraged character start to diminish by 2014. In 2018 KUKA had about 14,000 employees spread in 39 different countries.

Table 5. KUKA AG financial highlights 2008 - 2015, in thousands EUR

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current assets</td>
<td>697,850</td>
<td>555,789</td>
<td>821,470</td>
<td>911,400</td>
<td>959,400</td>
<td>1,150,800</td>
<td>1,309,100</td>
<td>1,689,200</td>
<td>1,011,876</td>
</tr>
<tr>
<td>Total assets (TA)</td>
<td>865,478</td>
<td>726,221</td>
<td>984,738</td>
<td>1,078,000</td>
<td>1,137,400</td>
<td>1,377,100</td>
<td>1,979,500</td>
<td>2,381,700</td>
<td>1,316,267</td>
</tr>
<tr>
<td>Non-current liabilities</td>
<td>274,812</td>
<td>293,113</td>
<td>398,188</td>
<td>380,800</td>
<td>405,900</td>
<td>502,500</td>
<td>517,200</td>
<td>631,600</td>
<td>425,514</td>
</tr>
<tr>
<td>Current liabilities</td>
<td>377,132</td>
<td>272,283</td>
<td>388,465</td>
<td>444,800</td>
<td>434,000</td>
<td>495,500</td>
<td>921,200</td>
<td>1,017,600</td>
<td>543,873</td>
</tr>
</tbody>
</table>

\(^8\) Of note, 2007 also saw the introduction of KUKA (and the world’s) largest and strongest IR, the KR Titan.
Comparable to COMAU’s case, KUKA’s set of patent-based measures exhibit shifts and breaks that align with the above narratives. Our examination suggests the following: a) the firm sustained high technological diversification from 1991 to 2015 (see Figure 1), b) a marked reduction and shift in its technology mix occurred in the mid-2000s, and c) a behavioral shift in its local knowledge vs. distant knowledge search also around the mid-2000s.

**Figure 4:** KUKA AG Technology Profiles 1991 / 2014 (IPC and NACE economic activity)
Select technological profiles of KUKA from 1991 to 2015 (see Table 4) demonstrate the richness of its technical capabilities. Among the enterprise’s 66% of classifiable technologies in the Patel-Pavitt matrix, 18% are core technologies, 11% are niche, 14% are background, and 23% as marginal. Particular on the mid-2000s technology mix shift, KUKA underwent a more expansive overhaul – there were substantial reductions in the background and core technologies. In contrast, there was a marked increase in marginal and niche technologies. Similar to COMAU, KUKA also exhibited capacity-building in computer and electronics production throughout. As a final note, it is interesting to observe how certain technologies have become irrelevant in the company’s capabilities. Back in stock-year 1991, the company had technical strength in the economic activity of fabricated metal production and military production. Over time, these have been relegated into the background until they became immaterial.

Regarding the firm’s propensities for either local or distant knowledge search (see Figure 5), the analysis does not support the predicted inverse local-distant search dynamic. From the early 2000s up until recently there is a upward trend in the scope of the external search, coupled with a relatively stable self-citing behavior (10% of made citations).

V.C. The mid-2000s restructuring among robotics firms: is it coincidental?

The technological and behavioral shifts of COMAU and KUKA around the mid-2000s demand further investigation. Looking into the automotive sector, the long-standing primary market for automation, provide indications that the crises and restructuring of the automobile industry had a major demand shock on the robotic sector.
The state of the global automotive sector around the early 2000s mainly depended on the robustness of demand in the Americas and Western Europe (which were already at their limits), as the Asian and other emerging markets were only beginning to emerge (UK House of Commons, 2004). Among these markets, the US market was the most valuable because the country hosted some of the world’s largest car manufacturers and a significant demand for vehicles. For robotics enterprises, the US was equally important because its car companies always maintained significant capital spending plans and had a strong inclination for industrial automation (FIAT Group, 2005; KUKA AG, 2004). While Western Europe was equally valuable, the market was already mature and only had a modest room for growth (although high growth was expected in the new EU countries in Eastern Europe at the time) (KUKA AG, 2004).

Because of this sectoral dependency, the US car industry’s demand crunch was able to reach the robotics manufacturers. The crunch was brought about by several factors, including the overproduction of vehicles (that oversupplied the market), declining car affordability, shifting consumer preferences from new to used vehicles, and continued entry by Asian car manufacturers (even in vehicle segments that were traditionally dominated by American car companies) (Carson in Klier, 2004; US International Trade Administration, 2005; Reynolds, 2017). The resulting increased competition steadily eroded the high profit margins that the US car makers previously enjoyed. These led them to prioritize cost reductions, close and restructure manufacturing plants, cutback in capital spending, and postpone automation plans (UK House of Commons, 2004; US International Trade Administration, 2005).

The European market could not mitigate the contraction’s effects because the concurrent rapid rise in oil prices offset potential increases in car demand in the continent (European Parliament Director General for Research, 2001; KUKA AG, 2005). Furthermore, commodity super-cycles (mainly brought about by China’s significant demands for such goods) led to a comparable skyrocketing of prices in essential inputs (i.e. steel) in robotics production (Magne & Frécaut, 2009).

Together, these suggest that the mid-2000s brought about a ‘perfect storm’: robotics companies were plagued with both supply- and demand-side pressures. The shrinking demand in traditional markets and the rising business costs forced robotics producers to rethink their operations. While opinions regarding the vulnerability of the business to business cycles vary (see Management Discussion in COMAU’s Annual Report 2004 and KUKA AG’s Annual Report 2004 for contrasting perspectives), there was a consensus among automation solutions providers to diversify their demand portfolio and to increase their products’ value propositions.

VI. Discussion and conclusions

Through the research, we sought to understand how contemporary and relatively high-technology enterprises, such as robotic companies, have been developing capabilities and adopting the appropriate exploratory strategies necessary for survival over time. We were interested to uncover evidence that are suggestive of the companies’ preparations in relation to future trends, such as the emergence of interactive robots and digital manufacturing.

The methodology adopted in this paper aims to offer the reader some evidence to better understand European incumbent robotic firms’ innovative behavior. A more nuanced understanding of past actions is indeed needed to be able to foresee future advances in an industry that is most likely going to be the cornerstone in the development of digital manufacturing and of a large number of
service industries (not discussed in this paper). The literature review and the evolution of the robotic industry enable us to portrait incumbent robotic companies as conservative organizations deploying incremental innovation strategies that is heavily dependent on the requirement from their users. However, recent developments in the broader sector, opened the way to new high-tech companies that explore a new opportunity set offering to the market new radical innovation and creating new markets. Which of these better captures the behavior of the two leading robotic companies in Europe? How are the two companies responding to current challenges to maintain their competitive advantage? Are the two companies putting forward similar innovative strategies?

The constructed case studies indicate that our focus firms have been cognizant about the need to adapt, although the actual shift have been slow. Through stylized facts derived from patent data, it became apparent that shift competencies take time and that accumulated capabilities are often retained. While we only crudely capture the evolution and adoption of background and niche technological competencies in our studied firms, we strongly find that there is a relative consistency in the development of core competencies. Company archives further reveal that external economic shocks and market expansion provide stronger impetus for organizational change.

The results indicate that high-technological diversity is a core feature of large European robotic firms. There is no evidence to suggest that they are inclined to further increase this diversity when a new technological opportunity set arises. Moreover, pairing this data with the enterprises’ technological profiles indicate that this high mix are mostly composed of a large set of marginal competencies and a smaller set of core competencies. Together, these give more credence to the argument that robotics firms’ capability-building are more likely for the maintenance of sufficient absorptive capacities than for the increased mastery of technical skills (which the ‘learning-by-doing’ dynamic predicts). Firms’ current knowledge bases seem suited not for pursuing revolutionary innovations but for guaranteeing the comprehensibility of developments in other technological areas. These observations are more comparable with recent research that finds the robotics sector requires actors to be highly relational and to have capabilities that bridge boundaries across disciplines, industries, applications, and knowledge (Leigh & Kraft, 2016). As a side, stylized facts suggest that core competence-building (i.e. case of computer-related capabilities) takes a significant amount of time.

The study offers limited support to the idea that contemporary robotics firms increase their distant search and decrease their local search to be able to respond to ongoing and anticipated changes (such as, the increasing need for software-related capabilities in robotics products). COMAU does not highlight any significant rebalancing while the trend of KUKA fits well with the noted development in the industrial landscape. The analyses only observe the tradeoff between local and distant search (or the exploitation vs. exploration dynamic) for limited periods. Also noteworthy is the parallel increases in both the search scope and local search tendencies of COMAU around the mid-2000s since this shift is seemingly driven by COMAU’s acquisition of other companies that is has previously cited in its patent applications (i.e. Renault Automation, Sciaky Industries).

A level of stability exists across all derived measures. Apart from the notable stability in technological diversity, there are comparable (albeit limited) consistencies in the other measures (i.e. the relatedness of developed core competencies, the steadiness of the search combinations). Collectively, these affirm the routinized and cumulative nature of the evolutionary firm. Similar to the observations that Ahuja & Katila (2004) made regarding chemical firms, the studied robotics
firms exhibited a strong tendency towards maintaining established knowledge-acquiring activities across time. Once again drawing parallels with Ahuja & Katila (2004), changes in these enterprises are inertial (in that they take place incrementally) but does carry momentum when undertaken.

However, our qualitative and quantitative exploration on the innovative behavior of two leading robotic firms underscores the effect of context specificities (and how it brings about heterogeneous firm responses). COMAU has maintained a conservative approach with a significant refocusing on core activities during the mid-2000s followed by an attention to economic performance while KUKA has showed a stronger inclination for technological diversification.

COMAU’s conservatism might be explained by its extensive association with the FIAT Group (and now, the FCA Group), as its innovative behavior may have been significantly influenced by its parent company’s corporate strategy (i.e. the modernization of Chrysler’s plants in the FCA Group’s during the early years). As such, it may also help explain we were only able to gather a small subset of its patenting output, as much of it may be concentrated in the FCA Group’s designated R&D laboratories (a cursory investigation reveals that Centro Ricerche has had a substantial patenting output in the past few years).

News in recent years suggest that the FCA Group is following a strategy of listing and selling some of its most valuable controlled companies (see the rumored listing of Ferrari and sale of Magneti Marelli) to raise capital – it might be that COMAU might very well be the next one in line.9 The willingness of the FCA Group to sell COMAU may be attributable to limited R&D activity already being carried out in the company. Moreover, perusing a risky diversification strategy could have impacted negatively COMAU’s books, thereby possibly making it less attractive to future investors.

In contrast, KUKA, after its restructuring, refocused on its robotics production diversifying in more advanced robotic fields. KUKA leveraged its expertise in the field and expanded in non-traditional robot applications, such as interactive robots and medical robots via various acquisitions in Reis Group and Swisslog Holding AG. As such, KUKA was able to overcome its non-familiarity in these areas and by-pass the requirement of lengthy capability-building. In January 2017, the Midea Group has bought 74.55% voting stocks of KUKA for EURO 4.5 Billion; this has been a strategic investment for the Chinese group as the potential for growth of the Chinese robotic market is very high.

More on the restructuring processes, the striking abrupt shifts in behavior of the two firms highlight the stronger impact of internal reorganization relative to any environmental stimuli. Internal restructuring brought about the most sweeping organizational changes. However, our investigation is unable to determine the exact relationship between the two. It must be noted that reorganization often effects sweeping changes in every aspect of the firm. As such, changes in these other dimensions, such as in employee count or firm activity, may also contribute to the shifts in knowledge-related heuristics. Future research may direct the preceding analyses to several directions. For one, succeeding studies may draw explicit and quantifiable relationships between the selected set of measures on innovative behavior and the firms’ competitive advantages or performances.

9 Such strategy can result in a reduction of the debt of FCA but at the same time in a loss of control of most valuable competences in the area of digital manufacturing.
The unexpected observations also call for further investigations. Possible attempts may be made towards disentangling and isolating the effects of intra-firm change (in particular, restructuring programs and M&A deals) in modifying the enterprise’ overall innovative behavior. There is already a growing set in the literature that is exploring the particular effects of M&A activities in innovative behavior (among others, Cloodt, Hagedoorn, & van Kranenburg, 2006), with an increasing number particularly focused on M&A strategies for pharmaceutical and life sciences companies (among others, Prabhu, Chandy, & Ellis, 2005; Mittra, 2007). Firms faced by radical technological change have used acquisitions as a strategy to rapidly acquire new sets of competencies. Another equally relevant examination relates to determining the effect of the firms’ position within their affiliates’ supply chain (or even in the broader global value chain). Being part of a large network of affiliated companies (i.e. COMAU’s case) against being an individual ‘retailer’ of capital goods (i.e. KUKA’s case) may have had an effect on their innovative heuristics.

Overall, all these observations seem indicative that robotics companies are not the harbingers of a revolutionary future they are commonly regarded as; they normally favor continuity and are likely to remain in familiar territory. While these enterprises are attentive of the current developments in their external environment, they are highly selective of those that they assimilate into the established operations. High-technology firms conservatively respond to external stimuli; internal shifts bring about more noticeable and abrupt changes in innovative propensities. More broadly, they add to the many examples in the history of technology that suggests the lengthy process and organizational boundedness of technological progress. Passing from the moment of first appearance of a new technology – e.g. smart robots – to mass production requires major accumulation of new technological knowledge within producing firms as well as significant organizational change in adopting firms. In some cases, incumbent firms are not able to adapt (see digital photography and Kodak) in other acquisition of small innovative companies allow the dominant players to survive (see the evolution of the pharmaceutical industry and the biotechnology challenge).

The above notion of the firm has important business and policy implications. The accounting focus in industry peers’ actions and development during benchmarking exercises may be limited in providing the firm with the necessary perspectives for sustained growth. Contemporaries may also share the same shortsightedness in anticipating external threats and conservatism in searching for opportunities. Setting courses of action based on existing paradigms may inevitably link the firm’s fate with that of the broader industry.
References


