Diversity in patterns of industry evolution: the emergence of the service robot industry in Japan

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Abstract

How do new industries emerge? The aim of this paper is to provide an answer to this question by focusing on the knowledge dimension of this process. We first argue that there is a sectoral bias of research which has equalized new industry emergence with only a selection of new industries, especially the software and biotechnology industry. In this paper, we focus on the service robot industry. We analyze its institutional properties, its knowledge properties, and the role of collaborations. We find that the emergence of service robot industry is, contrary to biotechnology and software, triggered by established technical leaders, and less by new firms. Using Japanese patent data, we also show that the service robot industry, while being a new industry, possesses cumulative characteristics. As the emergence of this industry matches to the characteristics of Japan's institutional and knowledge regime we essentially argue that the popular association of certain institutional paths with a lack of innovativeness is erroneous. We conclude that industry emergence in intrapreneurial regimes seems to be distinctive from entrepreneurial regimes.

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Key words: new industries, entrepreneurial regime, path-dependence, robot technology, Japanese innovation system, varieties of capitalism.

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1 Introduction[2]

At least since the 1990s, many papers on new industry emergence stress the role of new firms and linkages to them. Generally speaking, these papers not only assume underperformance of those innovation systems that do not offer an appropriate environment for new firms, but also claim a paradigmatic shift towards an "entrepreneurial regime", characterized by turbulences, a massive number of new entrants and a reduced role for large firms (Audretsch , Thurik 2000 and 2001). Such a view implies that those institutional regimes possess comparative advantages that enable small firms to evolve, to exit or to survive. A similar argument on the competitiveness of entrepreneurial regimes can be found in the recent literature on coordinated economies which argues that due to a lack of adaptation, coordinated economies are increasingly inefficient. In this view, Japan has, due to its specialization on cumulative technologies, an inherent inability to create new industries (Anchordoguy 2000; Aoki 2000; Collinson and Wilson 2006; Cottrell 1996; Goto 2000; Nezu 2004). We assume that the reason for these claims is a sectoral bias of research which has equalized new industry emergence with only a selection of new industries, especially the software and biotechnology industry. These industries are indeed in need of an appropriate environment for new firms.

However, contrasting to the claim that new firms and collaborations with them are perhaps not the sole, but at least the most critical locus of innovative activities (Aoki, Takizawa 2002; Arora and Gambardella 1990; Giarratana 2003), we argue that it is important to be more sensitive towards the diversity of institutional regimes and of technological properties of new industries. To put it differently, this paper proposes an alternative view on the emergence of new industries. We argue that new industries emerge in a path-dependent way in that they are matched to established institutional and knowledge regimes. Such matching processes, however, have to be analytically separated from underperformance.

We are certainly not the first to argue that the stable nature of institutional and technological regimes does not *per se* become a barrier to industrial dynamics. In a very general approach, already David (1997, 2007) conceived path dependence as a dynamic branching process. Since then, as a reaction towards the overtone of systemic inertia, a rich literature on the resources and conditions of systems' adaptability has been developed (Amable 2004; Bassanini and Dosi 1999; Brouillat and Lung 2009; Hall and Thelen 2009; Morgan and Kubo 2005; Streeck and Thelen 2005; Tombe 2008). More specifically related to industrial dynamics, the literature on technological regimes stressed since it beginnings that regimes and trajectories induce different innovative outcomes (Audretsch 1995; Malerba 2007; Nelson and Winter 1982). Based on the notion of regimes, proponents of the varieties of the capitalism

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approach argue that also coordinative economies possess an inherent ability to give birth to new industries, namely when firms specialize on new industries' subsectors that match to the established regime (Casper and Kettler 2001; Casper 2003; Casper and Whitley 2004). We are building upon and attempting to reconcile these prior works on path dependence, on technological regimes and on the varieties of capitalism.

Meanwhile, we also go beyond the prior literature in a number of ways. First, we show that established technical leaders have been the major actors in triggering the emergence of the industry. New firms have certainly played a role but compared to the role of large firms, they are definitely not the key actors. Obviously, there is no "one best practice" institutional regime for an industry emergence.

Second, we show that the new service robot industry possesses cumulative properties despite being a new industry. While being aware that this is only one case, we question the implicit assumption that new industries are necessarily radical-destructive in nature, and thus in need of "entrepreneurial regimes". An "intrapreneurial regime" characterized by large firms which enter the industry via diversification is an alternative option.

Third, we show that collaboration plays also an important role in intrapreneurial regimes.

Finally, we enrich the prior literature through the case of an industry that evolved in Japan – because, and not despite of path dependence characteristics of its innovation system. Hence, it is less inherent institutional change (at least in terms of the industrial organization we focus upon) that changed the Japanese system into a more entrepreneurial one, but more the activation of given paths. Obviously, path dependence can lead to creative outcomes. In contrast to Germany (Casper and Kettler 2001; Casper 2003; Casper and Whitley 2004; Herrmann 2008), Japan has not yet been subjected to this level of detailed analysis and we hope our research contributes to filling the gap.

Overall the paper reveals the importance of considering in more detail what is meant by path dependence and how this relates to the emergence of new industries. There is a growing body of work in the German context that reveals the importance of these issues specifically in order to understand the trajectory of economic systems (Deeg 2005; Hassel and Beyer 2001). Further work along these lines may contribute to a more refined understanding of how innovation systems are constituted, what role path dependence plays, and how and why a variety of institutional and technological regimes enable different patterns and types of path dependence. We hope that this will reinforce the broader theoretical argument that institutional analysis does in fact need to develop a more refined understanding of how the elements in a path are constituted and how path dependence actually operates.

The analysis of the Japanese service robot industry was undertaken with a three-fold empirical investigation. First, we carried out a patent data analysis. We use about 13,000 patents that have been applied between 1993 and 2004 in the field of service robotics in Japan. With these data, we are able to identify the key actors in the sector and to distinguish between existing and new knowledge. The Japanese patent data also enable us to identify knowledge relatedness, which is used as a proxy for cumulativeness. Second, we gained qualitative data from a total of 19 interviews conducted between March and December 2006 in firms, research institutes, business associations, ministries and public institutes. Third, we use sectoral reports of ministries and industrial associations (e.g. JARA, 2001; JPO, 2006; METI, 2006, see app. 1).

The remainder of the paper is organized as follows: In section 2 we discuss concepts of path dependence and of institutional and technological regimes, and relate them to the emergence of new industries. In section 3 we present data and methods. In chapter 4 we analyse the emergence of the service robot industry with patent data. We restrict ourselves to a more descriptive analysis of the sector, focusing on institutional and knowledge properties. Section 5 discusses and extends the results.

2 Path Dependent Patterns in the Emergence of New Industries: Entrepreneurial vs. Intrapreneurial Regimes

2.1 Emergence of New Industries

Modern economies are characterized by the emergence, development and decline of industries (Malerba, Orsenigo, 1995). The key variables that have proved to be relevant for the emergence of industries are existing knowledge bases, new knowledge bases, and new markets (Malerba 2007)[3]. New industries are emerging industries in an early stage. This means that often a market is not yet established and therefore only few products exist, so that new industries can only insufficiently be grasped by statistics based on products classifications. While being aware that knowledge and markets are interlinked, we focus in this paper only on the aspect of how new knowledge emerges, and omit the role of markets in the process of industry emergence. This new knowledge is essential as new industries are not "simply an extrapolation of a previous technology" (Rose-Anderssen et al 2005) but based on new knowledge.

As far as it relates to the emergence of new industries, research has mostly focused on the software, biotechnology and ICT industries; other new industries such as the service robots

[3] See the rich literature on "demand pull" and "technology push" as drivers for innovation (Chidamber, Kon 1994; Walsh 1984).

or the environmental industry have been less in the focus.[4] We assume that due to this empirical bias, too much of the academic literature concentrates on institutional conditions that are supportive for these "new economy" sectors (Audretsch et al 2001; Motohashi 2005; Powell et al 1996, Pisano 1991; Shane 2001). Since we are interested in a better understanding of how evolution patterns differ, we select the service robot industry for our analysis, which is expected to have, as being part of the machinery industry, different properties.

2.2 Key Variables for the Emergence of Industries: Institutional and Knowledge Regimes

2.2.1 Institutional Regimes: Entrepreneurial vs. Intrapreneurial Regimes

Inspired by the contribution of Ostrom on endogenous institution formation (2005) and transferring it to the case of new industry emergence, we conceive (existing and new) knowledge as an outcome of institutions. Our starting point are therefore institutions, which shape firms and non-firms behavior, and which induce distinct and institution-specific outcomes or, more specifically, knowledge bases. Depending on the evaluation of the outcome, firms may strategically reinforce the respective institutional regime in which they are embedded.

The varieties of capitalism literature differentiates between coordinated and liberal market economies (Hall, Soskice 2001). Recent papers on competitiveness and growth regimes, inspired by the performance of the Silicon Valley model, implicitly refer to this classification as they argue that "entrepreneurial regimes" with a market-oriented industrial organization, allowing for volatitily, dynamics and turbulences by vividly entries and exits, and close linkage to the science system, inter alia via academic spin-offs - a regime which *de facto* very much resembles the liberal market economy type – is the "optimal" growth regime. The alternative model has been termed as "managed"or "routine regime". In short, this regime is characterized by a hierarchy of innovative firms with a high degree of stability and a low rate of innovative entries, implying a less need for risky capital and mobile labour markets which very much resembles the coordinated market economy type (Audretsch , Thurik 2000 and

[4] A short glance at the Social Science Citation Index indicates the weak interest in the robotics/robot industry compared to "new economy" industries. Under the keywords "software" resp. "software industry" we found by far the most entries with 7.235 respective 729 entries; under the keyword "biotechnology" resp. "biotechnology industry" we found 1.723 resp. 728 entries; the respective data for information and communication technology are 2.394 / 239 entries. Robotics/robots have only 433 / 20 entries despite that this industry started to emerge in the 70s (data for 2000-2010; as of May 25th, 2010).

2001; Audretsch 1995; Nelson and Winter 1982). In order to overcome the normative tone, we suggest an alternate term for the "managed regime": the "intrapreneurial regime" in which corporate venturing is the key factor[5],[6]. The Japanese innovation system belongs to this group: Its institutional setting is characterized by large, established technical leaders, the so-called J-firms, developed internal labour markets, and an internal training system that aims at the intermediation of coordinative and integrative skills (Koike 1995; Lam 2002; (Aoki 2008; Nonaka and Takeuchi 1995; Porter et al 2000). Table 1 summarizes these features.

-Table 1 about here -

A key factor of the entrepreneurial regime is the substantial role of R&D and innovation networks which has been well documented and is now the object of a vast literature (Arora and Gambardella 1990; Gulati 1995; Hagedoorn, 2002; Mowery 1988; Powell 1996). Such collaborations enable their members to bring different technological specialization and heterogeneous knowledge together and to combine them (Boschma 2005; Mowery et al 1998; Nooteboom 1999a, 1999b and 2000). In a similar vein, Malerba (2007: 692) states that "the relevance of collaborations in innovation and R&D networks is due from the broad recognition that R&D and innovation are highly affected by the interaction of heterogeneous actors with different knowledge, competences and specialization". The fact that networks are a key factor is a striking contrast with the historical observation of firms carrying out research internally, and relying on external collaborations only for simple functions (Mowery 1983; Nelson 1990)[7]. We thus know from the literature that collaborations are a key factor in

[5] Sincere thanks go to Sebastian Schäfer, who has coined this term in cooperation with one of the author's book on institution and innovation (Storz, Schäfer 2011).

[6] In some papers, the entrepreneurial regime is associated with a growth regime and the Schumpeter Mark I regime, the intrapreneurial regime with a managed regime and the Schumpeter Mark II regime. Often, they are associated with different stages of development: Schumpeter I regime for developed economies, Schumpeter II for developing economies (Audretsch and Fritsch 2002; van Stel et al 2005). It is also illumative to see that the creative-accumulative regime was also termed as "routinized regime" (Audretsch and Fritsch 2002). Malerba (2007: 691), in contrast, argues that the Schumpeter Mark pattern may also be replaced by a Schumpeter Mark I.

[7] The relevance of collaborations has been recognized by resource based theories (Nooteboom et al 2006), game theory/transaction-cost based theories (Williamson 1981) and evolutionary economics (Malerba 2007). Gilsing et al (2008) show that the advantages of heterogeneity are not unlimited: a too high degree of heterogeneity reduces the firms' absorptive capacity.

the emergence of new industries. But since much of the literature is inspired by new economy sectors that emerged in entrepreneurial regimes (Arora and Gambardella 1990) we do less know about collaborations in intrapreneurial regimes. [8]

2.2.2 Knowledge Regimes: Creative-Destructive vs. Creative-Cumulative Regimes

Institutional regimes incentive actors in specific ways. Thus, the outcome – here: knowledge – depends on the respective institutional regime. In accordance to the two institutional regimes introduced above – the entrepreneurial and the intrapreneurial regime - , knowledge bases can be differentiated into two distinct "knowledge systems" (Winter 1984) or "technological regimes" (Nelson and Winter 1982) which differ in regard to technological opportunities, appropriability conditions and knowledge properties[9]. At the poles are the "creative destruction regime" and the "creative accumulation regime". Creative destruction regimes are characterized by a higher level of opportunities and appropriablilty and a lower level of cumulativeness whereas creative accumulation regimes are characterized by a lower level of opportunities and appropriability and a higher level of cumulativeness. We focus in this paper on the aspect of cumulativeness.

The entrepreneurial regime is characterized by a high instability in the hierarchy of innovative actors. Hence, knowledge is more easily destroyed, and learning via accumulation plays a lesser role. The industries in this regime can be characterized as competence-destroying since they build on scientific bases that differ significantly from the existing knowledge base of the established industry (Powell 1996: 117). Hence, with the creative-destructive regime, industries such as packaged software and biotech products are associated (which in popular association are often equalized with the total software and biotech industry).

[8] Due to a lack of academic spin-offs and formal contractual relationships, it is often believed that Japan's science system is "in-house" oriented (OECD 2006b). However, university-science relations are in fact dense but due to their informal nature difficult to measure. They crystallize inter alia in common research projects (Kodama and Suzuki 2007) and co-authored papers, but less in academic spin-offs (which are even overtaking the U.S., compare Pechter and Kakinuma (1999) as well as Odagiri (2006)).

[9] Also called "learning regime". We refer with these three characteristics to Malerba (2007). While there is a consensus on the existence of knowledge regimes, the elements which make up the regime are discussed. For example, Castellaci (2007) adds the degree of openness to foreign competition and the size of the market (the level of skills is subsumed in Malerba's description of work organization), and Lee and Lim (2001) add the access to foreign knowledge bases (in Malerba's paper, frequency of innovation and uncertainty is implicitly subsumed under knowledge properties).

In contrast, the knowledge base of creative-cumulative regimes is characterized by competences which are localized and cumulative in nature. Cumulativeness refers to the idea that actors have to solve a series of related tasks in some sequences, and then, while solving the tasks, speed up learning by using information or knowledge obtained from solving previous tasks. Put it simpler, the results of prior learning facilitate further learning (Bharadwaj, Kandwal 2008: 113). Technological cumulativeness thus expresses "the degree by which the generation of new knowledge builds upon current knowledge" (Malerba 2007: 690). Technologies associated with the creative-cumulative regime are mechanical, electronic, and transportation technologies (Marsili, Verspagen 2002; Malerba, Orsenigo 1995; Breschi et al 2000; Harhoff et al 2011), and industries associated with it the transportation, electronics, machinery and robots industry, as well as subsectors in typical "new economy" industries such as platform technologies in the biotech or the embedded software industry (Casper and Whitley 2004). In most of these industries, coordinative economies like Japan (or e.g. Germany) possess comparative advantages (Casper and Whitley 2004, Storz 2009) [10]. It should be kept in mind, however, that even if similar models of behavior can be found, industries are not uniform in terms of how firms learn and innovate so that also different patterns can be found on four-and five-digit levels (Leiponen, Drejer 2007).

Thus, there are two different knowledge regimes, and embedded firms tend to innovate in their specific logic[11].

2.2.3 Path Dependence of Regimes by Path Activation

As technological regimes themselves are in need of institutional support, embedded actors may reinforce their respective institutional regime under the condition that it is supportive to the established knowledge base. This may takes place intentionally or unintentionally, but induces feedback loops between the institutional and the knowledge regime of an economy.

The lower necessity of accumulating knowledge explains why the creative-destructive regime is characterized less by established technical leaders but more by new firms, many of

[10] In some new economy sectors, there are only estimations due to insufficient data. In embedded software, a new economy sector, sometimes national standards are used as an indicator. According to ERTL (2009), embedded operating systems based on the Japanese standard TRON have a market share of 41.42%. These data are confirmed by Midford (2006). However, it is not entirely clear to which degree this dominant position is also commercially used.

[11] That said, we are aware of institutional heterogeneity within systems (Storz 2008a; Weiss 2010: 345). Further, we acknowledge that the heterogeneity of firms has been increasing in Japan (Aoki/Jackson 2008; Lechevalier, 2007). We are also aware that the varieties approach and the approach on technological regimes assume representative firms that are cognitively aware of their technological and institutional environment (see Weiss 2010: 353, for a critical overview).

them linked to the science system or being themselves academic spin-offs. In contrast, creative-cumulative technologies which are characterized by cumulative and long-termed learning processes, are, simplifying the argument in a great deal, in need of institutions that enable firms to overcome a series of incomplete contract dilemmas (Weiss 2010: 343). Firms producing cumulative technologies thus tend to reinforce those institutions that enable them to overcome these dilemmas.

The mutual reinforcement between specific institutional and knowledge regimes should not be conceived as a technological determinism, but more as the result of a strategic selection of the embedded firm who searches for supportive institutions. Over time, regimes thus show quite stable patterns with different comparative advantages - the intrapreneurial regime in cumulative technologies, the entrepreneurial in radically new technologies. This also explains why still national pattern of innovation can be observed, despite the ongoing globalisation of production processes, the increasing role of multinationals and the growing heterogeneity of firms (Deeg and Jackson 2007).

This understanding of path dependence differs from many works which have focused on constrained choices of embedded actors, on market failures, and on technological and institutional factors that inhibit economically and socially desirable change. Examples include standardization economics (Liebowitz and Margolis 1995a, 1995b), economic history (Mokyr 1990), political economy approaches (Acemoglu and Robinson 2008), organization science (Collinson and Wilson 2006) and economic geography (Grabher 1993). More or less, these works equate path dependence with lock-in and QWERTY-effects (David 1997, 2007, Crouch and Farrell 2004). The assumption behind is that there are self-enforcing mechanisms so that only exogenous shocks may get the path changed. Since such an approach blends out the actor in an unrealistic way, recent research has reacted by focusing on interaction processes between institutions and actors, hereby bringing actors (Ostrom 2005) and institutional change (Streeck and Thelen 2005) back to institutional analysis. Increasingly it is acknowledged that path dependence is less as a specific reason for an inefficient outcome, but an open process where paths are created endogenously.

In order to convey this dynamic property better, we borrow the term "plasticity"[12] to indicate that paths do in fact have a wide range of choices and sources for endogenous change. We illustrate this property by analyzing the service robot industry, which emerged in an intrapreneurial path. More specifically, we apply the concept of plastic paths to the national-level of the Japanese innovation system. While there is an ongoing discussion as to which degree actors are cognitively aware of their institutional and technological environment, we start from the assumption that actors may activate the institutional path when it fits to their strategic interest. Due to feedback processes between institutions and knowledge, the

[12] Alchian (1988: 69) defines "resources and investments 'plastic' to indicate that there is a wide range of discretionary, legitimate decisions within which the user may choose".

concept of path dependence holds also true for institutional and knowledge regimes and industries associated to them (figure 1 about here). [13]

-Figure 1 about here-

2.2.4 Conditions for the Emergence of New Industries: What Can We Expect from an Intrapreneurial Regime?

The literature on the emergence of new industries has been strongly inspired by works on the entrepreneurial regime for the software, ICT and biotechnology industries. We have outlined its institutional characteristics above: The entrepreneurial economy is characterized by turbulence, diversity and heterogeneity, caused by a market-oriented industrial organization, open labour markets and risk capital, where new firms are the core actors.

What can we predict for the institutional and knowledge properties of a new industry in an intrapreneurial regime? As we do not know much about it, we formulated our expectations on combine the general insights on industry emergence and intrapreneurial regimes.

We argued that firms are embedded in stable institutional regimes which incentives the accumulation of specific knowledge stocks. First, as institutional properties and especially the industrial organization differs between regimes, we expect that less new firms are contributing to the emergence of the industry, but other actors. Second, we know for three cases – the biotech, the software and the game industry (Casper and Whitley 2004, Storz 2009) that also new industries tend to match to the established institutional regime. We thus expect that the service robot industry, despite being new, also possess cumulative characteristics. If both expectations are confirmed, we have to understand how some principles of discontinuity were introduced, that is, how new knowledge entered the industry Third, collaborations have been identified as such a key variable since they combine heterogeneous knowledge stocks, so that we also expect that they play a substantial role in new industry emergence in intrapreneurial regimes.

[13] The stable nature of regimes allows for clustering identifiable and relatively stable groups of nations in which representative firms describe in their exchange processes the system. Hall and Soskice (2001) group Japan as a coordinated economy; in Amable (2004) and Whitley (2005), Japan forms its own variety.

3 The Service Robot Industry: Data and Method

3.1 The setting: the service robot industry

The service robot industry is part of the machinery industry[14] which is commonly treated as being cumulative in nature. It is a new industry that corresponds, compared to industrial robots, to new uses and therefore potentially to new markets: service robots operate in an open and random environment, in interaction with human beings and are characterized by an ability of learning[15]. Hence, they must possess different technological capabilities, especially superior mobile functions and image processing functions. These new functions are mainly provided by the so-called next generation robot technologies (NGRT) which are thus a key factor for the industry's emergence. NGRT are 5 out of 23 core technologies of a service robot and contain mobile robots, artificial intelligence, control of mobile robots, image processing and sound recognition. The remaining 18 technologies are also used for industrial robots and classified as non-NGRT (JPO 2002, 2006). The classification of the JPO is confirmed by our own interviews with key actors in the Japanese robot industry (see appendix 1). In figure 2, we present a technological map of the service robot industry. It becomes obvious that new knowledge bases (NGRT) are built into a setting of existing knowledge bases (non-NGRT) with complex interrelatedness (compare also JPO 2002, 2006).

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[14] More precisely, service robots are together with robots grasped into ISIC in the four digit level 2816 (manufacture of lifting and handling equipment) or 2829 (manufacture of other special-purpose machinery). The class 2816 is part of section C (manufacturing), division 28 (manufacture of machinery and equipment), group 281 (manufacture of general-purpose machinery); the class 2829 of group 282 (manufacture of special-purpose machinery). Appendix 2 gives more details about the classification.

[15] Compare IFR (2010) which defines a service robot as a robot which operates semi- or fully autonomously, performing services that are useful to the well-being of humans and equipment, excluding manufacturing operations (IFR 2010). With this definition, manipulating industrial robots could also be regarded as service robots, provided they are installed in non-manufacturing operations. Service robots may or may not be equipped with an arm structure as are industrial robots. Often, but not always, the service robots are mobile. In some cases, service robots consist of a mobile platform on which one or several arms are attached and controlled in the same mode as the arms of the industrial robot. Because of their multitude of forms and structures as well as application areas, service robots are not easy to define." (IFR 2010)

-Figure 2 about here-

Patent applications for NGRT technologies are increasing, while patent applications of non-NGRT technologies are decreasing. 1999 were a turning point in that significantly more NGRT technologies were applied, so that the time of the industry emergence can be fixed to the end of the '90s (figure 3).

-Figure 3 about here-

Within the NGRT, especially two technologies are increasing, that is mobile robot and sound recognition, and the most drastic increase hereof in mobile robots [16]. On a consolidated bases, mobile robots and image processing are the two technologies with the highest patent applications (table 2).

-Table 2 about here-

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[16] There are two remarkable exceptions in non-NGRT-technologies: gripping hands where patent applications sharply increased until 2001, and safety devices whose application numbers are stable. Even if they are non-NGRT-technologies, these both classes are indirectly linked to service robots: Gripping hands may also be used for service robots, and safety is a crucial problem for robots in general and a special one for service robots operating in a random environment in interaction with people (table 2).

In the service robot industry, Japan possesses comparative innovative advantages. Table 3 reports cumulative accounts and growth rates of patents in the robot industry. While patent growth rates (except mobile robots) are higher in the USA than in Japan, the number of cumulative patent accounts in the five NGRT technologies is for Japan much higher than for the USA. We may interpret this in a way that the USA catches up, but that Japan is still the innovative leader (table 3).

-Table 3 about here-

Japan thus possesses comparative innovative advantages in NGRT[17]. It is thus an interesting case to better understand the sources of dynamics in paths.

3.2 Using Patent Data to analyze the Emergence of a New industry

Our empirical evidence is based on an original dataset of the Japanese Patent Office. To create our database, we merge two complementary data sources: The Industrial Property Digital Library (IPDL; koho text kensaku) and Standardized Data (seirihyôjyunka data) which are both provided by the Japan Patent Office (JPO). This data set allows us to study a 11-year period from 1993 to 2004, during which 13,614 robot related patents were applied in Japan. It also allows us to distinct between different organisations, including 1,790 firms, 118 universities and 74 public research institutes.

These data give a rather complete picture of the knowledge bases of the industry and their evolution. This is all the more critical for us since we consider knowledge as a key factor for industry evolution. Patent data also allow us to distinguish between existing and new knowledge which goes beyond a mere chronological perspective on patent application date. They also allow us to analyze the actors and thus the properties of the industrial organization in which the new industry emerges. Finally, we are able to provide a preliminary analysis of

[17] We here only refer to competitiveness in patent indicators. For products compare the category personal/domestic robots in IFR 2010 (pp105-110).

knowledge flows which is critical in order to get a better understanding of the knowledge properties of the industry.[18]

Having said this, we are aware of limitations of patent data use. First, patenting is a relatively upstream activity in R&D, thus most patents do not lead to new products. Second, depending on the actor's strategy, there may be the danger of strategic patenting (in the case of Japan, see Mahlich 2010) or, on the contrary, the underpatenting in order in order to avoid any disclosure of knowledge. For the service robot industry, we find evidence for both strategies (interviews). Third, large firms are overrepresented, partly because patenting is costly. This is particularly true in Japan, where only about 10% of patents are applied by SME, especially due to high associated costs (Kimura 2009; Yokoshima 2007). Fourth, knowledge is not limited to patents and includes much more informal activities. This holds especially true for Japan (Goto & Odagiri, 1997). Finally, Japanese universities had until recently no incentives to apply for patents (Motohashi, 2005).

Although these limitations exist, we believe that they are not critical to our investigation: First, according to industry's experts, strategic patenting seem to be less an issue in the service robot industry compared to other industries (JARA, 2001). Second, even if there is a bias towards an underrepresentation of SMEs, this problem is, compared to alternative methods –surveys and publication analysis – smaller, as at least in some industries, firms have an incentive to protect their technology (Lechevalier et al., 2007). Third, recent papers on patent applications of Japanese firms have shown a significant increase in the number of patent applications of universities and small firms so that patent data increasingly represent their R&D activities (Motohashi, 2005; Nagaoka, 2006). These points have been confirmed by our interviewees and by official reports (see appendix 1).

3.3 Analysis of Institutional Properties

The first dimension of our analysis concerns the industrial organization and the key actors in the service robot industry. A preliminary step has been to identify the actors based on the information we have on inventors. More precisely, we identify approximately 30,000 distinct individual inventors corresponding to the 13,614 patents we analyze. Then, we identify their affiliation to a certain type of organization at the time of the patent application. We did this either directly, based on the address indicated in the patent, or indirectly based on own investigation via search engines (e.g. ReaD of the Japan Science and Technology Agency). After having identified the organization to which the inventor belongs to, we could classify them into three types: firms, universities, and public research institutes. We found that the

[18] Malerba (2007) also provides some arguments for the use of patents (more specifically patent citations) in the analysis of industrial dynamics.

approximately 30,000 inventors belong to 1,790 firms (F), 118 universities (U) and 74 public research institutes (P) (totally 1982 organisations).

In order to be able to analyse the institutional regime of the service robot industry, we have to know whether large established firms or start-ups are the key actors. While we are not able to identify for the whole database the size of the organization (which may also have changed during time), we identified the names of the patent-leading 30 firms whose inventors applied for the patent. We then classified all firms founded after 1990 as start-ups. We then estimated the role of start-ups with the quality of patents they applied for. While being aware that the measurement of patent quality is a discussed issue, we here confined to the scope of protection (measured by the number of claims per patent). This allows us to identify, in a first approximation, the contribution of different types of firms to the emergence of the industry.

3.4 Analysis of the Knowledge Base in the Service Robot Industry

Our paper aims further at a better understanding of the knowledge properties of the service robot industry. The knowledge base consists out of NGRT and non-NGRT knowledge bases. When we refer in the following to new knowledge, we refer to NGRT[19]. Non-NGRT refers to existing knowledge. Referring to knowledge properties, we are interested on which knowledge bases NGRT and non-NGRT are built upon. In more technical terms, we are interested in patterns of knowledge flows. The best data to do so are patent citations (Malerba, 2007). However, even if our database contains data on (forward and backward) citations, it does not allow us to link them to technological fields (e.g. mobile robots). Therefore, we are forced to use a proxy for technological cumulativeness. We will use the IPC classification of patents as a proxy, being aware that this proxy is about knowledge relatedness among technological fields and not about knowledge flows. Our measurement of technological relatedness builds upon Jaffe (1986), who suggests to measure technological relatedness by looking at the distribution of patents in technological fields (e.g. by the International Patent Classification).

The IPC is an internationally agreed patent classification. Patents are classified by one (main or primary) and further (secondary or supplementary) classification codes of the IPC; these codes are attached to the patents by patent examiners of the respective issuing patent office. The main classification codes indicate the key characteristics of the main claim of the patent,

[19] We are aware that the term "technology" goes beyond the term "knowledge" as the former contains, inter alia, also artifacts. When we use NGRT or non-NGRT in the following, we use the word technology in the sense of new knowledge as we do rely here on the wording of the JPO which has coined these terms.

while the supplementary codes describe further features. At least one classification code of the IPC is assigned to every patent. Japanese robot patents are classified as B25J (the main IPC). We thus adopted a technology-oriented classification based on the different fields of technology of the International Patent Classification at 1 digit and 2 digits levels. Table 4 shows the definition of IPC code at 1 digit level.

-Table 4 about here-

In extracting those patents having a main IPC for NGRT (that is: B 25J), we can identify and tally supplementary IPCs. Then it is possible to aggregate or cluster those supplementary IPCs depending on co-occurrence of IPCs to describe related fields. To give one example: The patent 2004-253813 is a mobile robot patent applied by Honda in 2004. The main IPC of this patent is B25J 19/00, which indicates that it is related to mobile robots. Besides the main IPC, there are 9 other technologies to which the patent is related and to which supplementary IPCs refer to. In the case of this patent, the supplementary IPCs refer inter alia to "other robot technologies" (B25J 5/00), to "toys" (A63H 11/00; self movable toy figures/ A63H 11/18; figure toys which perform a realistic walking motion), and to "batteries" (H02J 7/00; circuit arrangements for charging or depolarizing batteries or for supplying loads from batteries).

3.5 Analysis of Collaboration

The third dimension of our analysis concerns collaborations. We are interested in the role of collaborations for the creation of NGRT. We therefore compare the role of collaborations for the creation of NGRT technologies, compared to non-NGRT technologies.

-to be finalized-

4 Results: How New industries Emerge in an Intrapreneurial Regime?

4.1 Analysis of Institutional Properties: Actors and Industrial Organization

The literature on "entrepreneurial regimes" argues that start-ups are a key variable for a new industry's emergence. As we find by analyzing the top applicants, the situation in the case of the service robot industry is rather different: When we rank the top applicants in numbers of patents, they all are established technical leaders. In the case of non-NGRT, we find the two major robot makers (Yaskawa and Fanuc) belong to the top three applicants. For these two companies as well as for Kawasaki Heavy industries (a leading robot maker which is number 6 in terms of non-NGRT patent application), the ratio of non-NGRT patents is more than 70% (table 5a). Also in NGRT, the top applicants are established technical firms such as Matsushita, Toshiba, Sony or Hitachi. Thus, the major players does not seem to be start-ups (table 5b).

-Table 5a about here-

-Table 5b about here-

This result confirms our expectation that established technical leaders are the key players in the new industry, especially since also the emergence of new knowledge (that is: NGRT) can be located in established technical leaders.

When we rank by the quality of their patents, the result is somewhat qualified, but still large firms are the key players: Among the ten majors actors, four are startups and created after 1990, and among the top 30 actors, 5 new firms. This is insofar not astonishing as, for sure, also in intrapreneurial regimes start-ups exist (vice versa, established large firms play also a role in entrepreneurial regimes). And, even with this very restrictive approach, large firms still appear among the major players. This becomes even more obvious when we enlarge to the top 30 firms. Also, non of the four new firms is an academic start-up which is characteristic for the biotech and software industry. Hence, we find it difficult to conclude that start-ups are the key players in the emergence of the service robot industry: start-ups are not non-existing, but probably not the triggering actor (table 6).

-Table 6 about here-

From tables 5 and 6 we get another important and unexpected result: Those firms that triggered the emergence of the industry mostly belong to sectors outside the robot sector, and especially to the electrical machinery sector (Matsushita, Toshiba, Sony, Hitachi, compare table 5). We also see that the ratio of non-NGRT patents is much lower for makers outside the robot technology sector (e.g. 61% for Matsushita and 20% for Sony, table 5a). Vice versa, the picture for NGRT patents changes drastically: The most important players of the robot industry (Fanuc, Yaskawa) do not even appear in the list of the top ten applicants (table 5b). Also, in our top 30 ranking with qualitative patent indicators they do not appear (table 6).

To summarize, major patent applicants in both NGRT and non-NGRT are large, established technical leaders. Their strong role contradicts with the literature on growth regimes which suggests that large firms have lost their role in innovation. In the creation of new knowledge – the NGRT technologies – these technical leaders mainly come outside from the robot industry, as patent applications originate from large firms of the electrical machinery and the transportation sectors. Obviously, the service robot industry in Japan is characterized by alternate patterns of entries, not in the form of exogenous start-ups, but in the form of endogenous diversification of outside actors. If this is true, we may have found an important mechanism of heterogeneity that goes beyond collaboration, and that may be distinct for creative-cumulative regimes, that is inter-industry diversification. This assumption is supported by the general notion that the strategy of Japanese firms in the exploration of new projects is characterized by diversification and less by independent new firms (Delios, Beamish 1999, Kodama 1986) as well as be recent papers arguing that corporate venturing as well as ventures outside existing organizations are of key economic and social importance (Parker 2009). That the new service robot industry has emerged outside the robot industry implies that new industries should not simply be conceived as a new branch of a given industry, but as a combination of heterogeneous knowledge stocks.

4.2 The Service Robot Industry: Knowledge Properties of a New, but Cumulative Industry

New knowledge is a key factor in the process of emerging new industries. Where does, in the case of the service robot industry, the new knowledge comes from? Let us first recall that the technological base of the service robot industry consists out of 23 technologies out of which 5 are new (NGRT), and 18 existing knowledge bases (non-NGRT).

As defined above, cumulativeness expresses "the degree by which the generation of new knowledge builds upon current knowledge" (Malerba 2007: 690). As "new knowledge" in our case is NGRT, "current knowledge" refers, in a narrow sense, to the existing knowledge bases of the robot industry (non-NGRT) or, in a broader sense, to existing knowledge bases outside the service robot industry.

If the service robot technology is cumulative in nature, we should expect that its NGRT technologies build upon the existing knowledge bases (non-NGRT). In other words, we should observe knowledge flows from existing to the new knowledge bases. We therefore check to which degree NGRT is built upon Non-NGRT. We already classified all robot patents into 23 technological fields. If NGRTs (the five new technologies fields) have a high degree of IPC codes related to non-NGRT (the 18 established technologies fields), then we interpret this as knowledge flows from non-NGRT to NGRT. Totally, there are 5442 NGRT patents. We find that 1547 patents out of them are related to non-NGRT technologies. In other words, about a quarter of NGRT patents (new knowledge) is related to the existing knowledge base of traditional robot technology. As there is no statistical criterion which degree of knowledge flows from current knowledge to new knowledge makes an industry cumulative, and as we are not able to compare the service robot sector with a non-cumulative sector, we only can conclude that there seems to be knowledge flows between NGRT and non-NGRT (table 7).

-Table 7 about here-

Going beyond the narrow definition of "existing knowledge", we analyze how much NGRT technologies are built upon knowledge bases outside the robot sector. We find that NGRT (as well as non-NGRT) are built upon technologies outside the robot industry (more technically: not from B 25) to a substantial degree. Again, we do not have a statistical criterion, but we can conclude that cumulativeness seems to play a role in that NGRT built upon other technologies to a considerable degree.

Further, we hereby got further interesting and unexpected result: Comparing between NGRT and non-NGRT we see that NGRT are built much more upon technological fields outside the robot sector. A simple t-test shows that difference is significant. More precisely, the ratio of patent counts by IPC shows that NGRT technologies are more built upon the technological categories A (human necessities such as sports, amusement/A 63), G (physics such as controlling, regulating, computing, calculating, counting, musical instruments/G05, G 06, G 10) and H (electricity such as electric communication technique H04). In contrast, non-NGRT technologies are related more to category B 25 (service robots)   (table 8).

-Table 8 about here-

Hence, there is a certain indication that cumulativeness seems to play a role also in new knowledge bases. Further, we got the unexpected result that the new knowledge base NGRT builds to a higher degree than non-NGRT upon knowledge bases outside the robot sector. The strong contribution of inter-industry relatedness is also confirmed by our interviews. Apparently, NGRT is based more on technologies that were developed in sectors outside the robot industry (such as electrical machinery or amusement), compared with non-NGRT technologies which are developed more inside the robot industry.

4.3 Analysis of Collaboration

The literature on new industries has emphasized the role of collaborations as a key factor for an industry's emergence. Some simple descriptive statistics indicate that the propensity to create new knowledge (NGRT) is higher within collaborations: We calculate the share of NGRT and non-NGRT patents for different types of patents for the whole period (1993-2004). On average, 39% of all patents are NGRT-related patents. Among all collaborative patents, 43% are NGRT and a simple t-test shows that difference is significant (table 9a).

-Table 9a about here-

As NGRT emerge from 1999, we conduct the same simple exercise for the period 1999-2004 and the results are even more striking: on average during this period, the shares of NGRT patents and non-NGRT patents are equal (50%). However, among collaborative patents, the share of NGRT patents reaches 53%, while in the case of on-NGRT patents, the share is only 47%. Again, t-test shows that this difference is significant at 5%. From this descriptive analysis, it is possible to conclude that collaborations seem to have been a key factor in the emergence of the service robot industry (table 9b)

-Table 9b about here-

To sum up, collaborations seem to be critical for the new service robot industry. While we are not able to analyse all collaborating firms' names of our database, we know from interviews that start-ups play a less role, but that large firms and universities are the main actors. External linkages to new firms thus do not seem to be a key factor in the industry's emergence.

5 Discussion and Extensions

5.1 Theoretical implications

While the empirical results of our paper are descriptive and address only the Japanese service robot industry, we think that they raise interesting questions about whether this industry is an isolated case, or perhaps an extreme case of a more general phenomenon. We believe that our study has two main theoretical implications. First, the findings have implications for the literature on industrial dynamics. Innovation research has emphasized the role of new firms in industry emergence. Our findings do not show that new firms are unimportant, but do highlight that the technological regime to which the new industry belongs to is critical. Second, the study challenges the literature on path dependence as lock-in and, more specifically the competitiveness literature which assumes that only certain technical regimes are appropriate for the emergence of new industries. The paper reveals the need and importance of giving more in-depth consideration to what is meant by path dependence and how this relates to processes of the emergence of new industries.

5.2 Limitations and Further Research

In order to obtain preliminary data on the emergence of a new industry with creative-cumulative properties, this study focused on the service robot industry. It should be kept in mind that this is only one case in one country, and that the findings may be sensitive to industries, the national context, or the particular firms studied. Future research should thus explore this question in other contexts. As it is generally known, there is a trade-off between cross-industries and cross-countries samples that are general and single or few industry/country samples that can have richer data and provide a high level of detail. Being exploratory in nature, this study chose the second option.

Our paper has further limitations: the most important one is perhaps that we choose a narrow approach, excluding a comparative analysis. Further, relying on patents introduces some bias, which have not yet been solved.

Further research should focus on the conditions that trigger the emergence of a new industry since this would enable us to make more precise predictions on the emergence of industries. This paper has elaborated that new industry emergence is affected by the institutional and technological regime in which it is embedded. This allows the prediction that new industries tend to "match"; that is, that they are affected by the institutional and technological properties of the established regime. But some basic questions are open. First, which role plays demand, in addition to our technology-push-related argument? For example, what is the role of demographic change in Japan? Second, which other new industries possess creative-cumulative characteristics?

5.3 Conclusion

There is only few evidence how new industries emerge in intrapreneurial regimes as research has focused upon typical "new economy" sectors like software and biotechnology. This paper explored the emergence of a new industry with creative-cumulative properties, the service robot industry, which possesses different technological properties than new economy sectors. We follow the recent literature in arguing that there are indeed distinct institutional and technological regimes, but that such a specialization should not be equated with inefficiency or lock-in effects since it is far from clear which institutional and technological properties new industries possess. In this paper, we analyzed an industry with cumulative characteristics, the service robot industry. Cumulative technologies are in need of distinct institutional configurations. We have called this configuration the "intrapreneurial regime" indicating that this regime is characterized by a distinct industrial organization that enables long-term interaction. The popular argument about whole innovation systems not fitting to new industries is, in our view, rather oversimplified. Matching plays a role, but in a more discerning way, where the distinctive technological characteristics of the respective new industry should be taken into account.

Drawing on the service robot case, we analyzed how new industries emerged in a creative-cumulative regime. We showed that start-ups do exist also in the service robot sector, but that large firms seem to be the primary locus of innovation. This does not exclude that new firms also play a role – as vice versa also large firms in the entrepreneurial regime play a role – but, at least based on our findings, we find it difficult to say that start-ups are the key players. Obviously, the service robot industry in Japan is characterized by alternate patterns of entries, less in the form of exogenous start-ups, but in the form of endogenous diversification of actors outside the robot sector. If this is true, we may have found an important mechanism of heterogeneity that goes beyond collaboration, and that may be distinct for creative-cumulative regimes, that is inter-industry diversification. We also confirmed that collaborations which are a key factor for industrial dynamics in entrepreneurial regimes are also a key factor in the intrapreneurial regime. To put it simply, the assumption that large firms are no longer the sole locus of innovative activity does, at least, not hold true for the service robot industry considered here. Hence, as far as policy is concerned, our results imply that the focus of innovation policy should no only be directed towards start-ups, but should also keep the role of established innovators in mind.

The case of the service robot industry seems to imply that new sectors reproduce the logic of the existing institutional and technological regime. This again means that industrial dynamics takes place in a relatively stable path. In order to describe this stable nature better, we prefer the term "path plasticity". In doing so, we aim at avoiding any association of intrapreneurial regimes with a lack of innovativeness.

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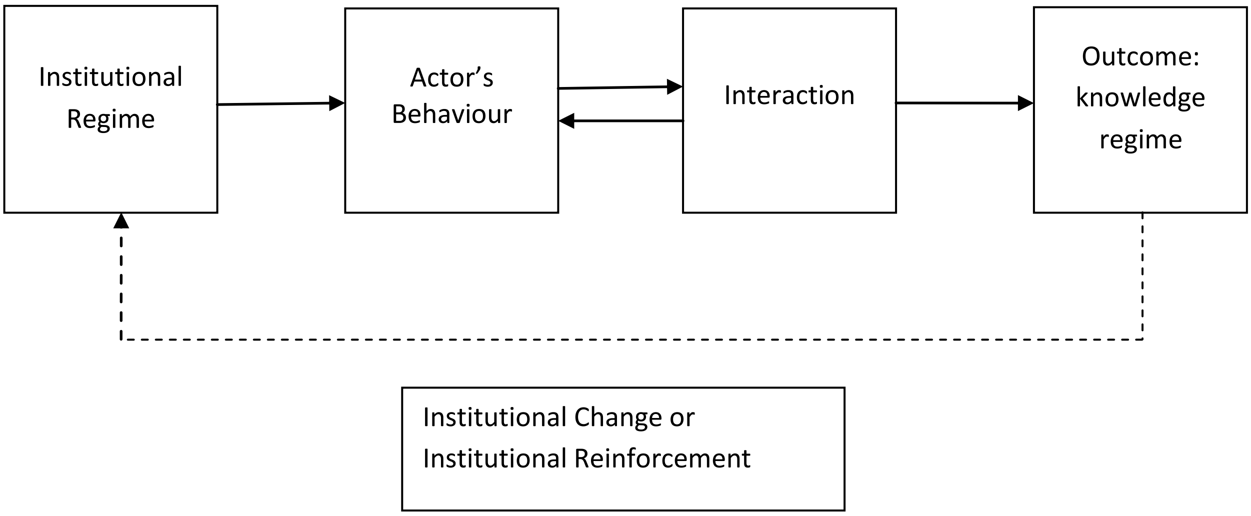
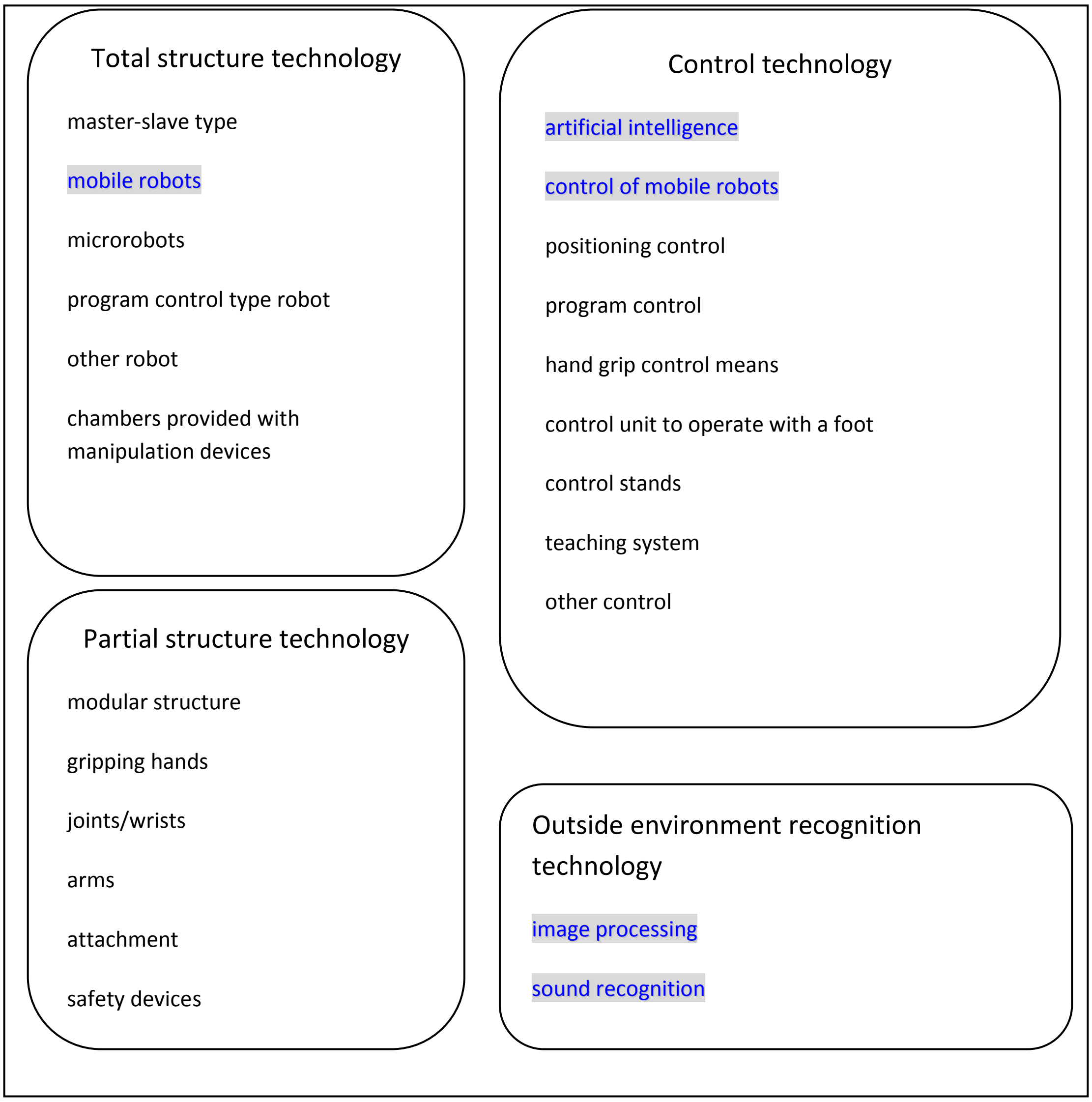
7 Tables and Figures

Figure 1: Institutional and Knowledge Regimes



Source: adapted from Ostrom (2005)

Figure 2: Classification of core technologies in the robot industry



Source: JPO (2002)

Notes:

(a) The technologies shaded are closely related to the technology of next generation robots

(b) The purpose of patents is unclear. Patents are applied in certain patent classes (e.g. in artificial intelligence) but it is by no way decided that this technology is not used by other sectors, in the case of service robots e.g. in transportation or industrial robots.

Figure 3: Number of patents applied in robot-related technologies in Japan between 1993 and 2004 with a distinction between NGRT (next generation robot technology) and non NGRT

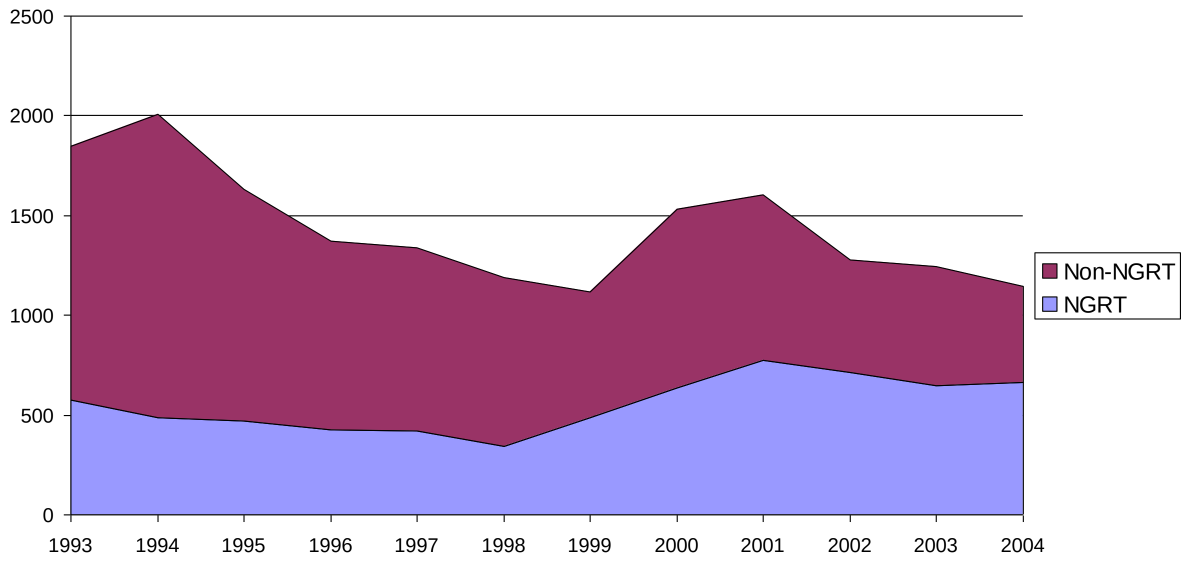


Table 1: Existing Knowledge Bases in the J-System and Their Institutional Regime

J-system: Existing Knowledge Bases and Institutions	
Training system	internal training in firms, long-term employment
Wage labour nexus	Internal labour market and training; 'consensus'; career inside firms; weak mobility; weak role of independent start-ups (including academic spin-offs)
Interfirm relations	Dense networks; long-term with primary suppliers; strategic investments; sponsored spin-off instead of external start-ups
Existing knowledge bases and industries associated with it	Transportation, electronics, machinery, embedded software, biotech platforms ("creative accumulation regime")

Note: J-firm: corresponds in more recent publication to the Hybrid I firms distinguished by Aoki et alii (2007): Based on an analysis of corporate governance, and use of capital and labour market, the authors refer to the dominant engineering industries such as transportation, electrics/electronics, machinery.

Table 2: Evolution of the number of patents applied between 1993 and 2004 by sub-categories

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
master-slave type	53	31	28	18	20	10	22	14	16	11	11	9	243
mobile robot	180	158	147	114	157	134	199	282	361	325	314	308	2679
microrobot	14	16	22	25	14	25	28	18	19	11	23	13	228
cartesian co-ordinate type	47	40	34	24	19	4	7	12	16	6	10	7	226
cylinder / polar coordinates type	7	9	9	9	7	13	9	6	5	8	6	6	94
multi-articulated arm	93	84	84	91	107	93	43	62	72	56	47	38	870
chambers provided with manipulation device	6	3	15	5	3	1	6	2	1	7	3	3	55
gripping hands	448	709	536	352	296	323	264	375	373	235	200	170	4281
joints/wrist	94	70	87	94	73	82	62	77	78	55	78	45	895
arm	35	27	39	32	46	21	10	20	9	11	14	10	274
safety device	61	59	38	38	44	52	34	50	41	44	64	56	581
artificial intelligence	33	30	9	21	19	12	21	31	32	22	29	25	284
control of mobile robot	113	99	83	81	74	60	62	55	65	88	61	81	922
positioning control	179	211	87	101	114	82	53	93	73	40	50	43	1126
program control	75	123	49	44	48	34	24	47	18	6	13	13	494
hand grip control	12	13	7	12	16	10	16	6	12	12	11	5	132
control stand	21	27	10	14	10	9	4	5	9	11	3	9	132
teaching system	130	95	117	85	100	84	49	112	86	52	68	50	1028
image processing	236	191	220	196	159	124	153	190	201	194	173	183	2220
sound recognition	11	10	12	14	14	15	52	77	117	84	69	69	544
Total	1848	2005	1633	1370	1340	1188	1118	1534	1604	1278	1247	1143	17308

Note: The technologies shed in yellow correspond to the next generation robot technologies (NGRT), which play a key role in the emergence of the service robot industry

Table 3: Comparison between Japan, US and Europe of patenting in robotics (1999-2004)

Category	Growth rate			Cumulative counts (1999-2004)		
	Japan	U.S	Europe	Japan	U.S	Europe
Toal structure technology						
master-slave type	0,86	1,08	0,60	95	25	16
mobile robot	2,10	1,63	0,94	867	242	136
microrobot	1,07	1,44	0,44	116	22	13
program-controlled robot	0,89	0,73	0,54	619	175	212
chambers provided with manipulation device	0,86	0,00	1,00	13	1	8
Partial structure technology						
gripping hands	0,52	0,95	0,84	1399	260	234
joints/wrist	1,00	0,79	0,80	551	84	106
arm	0,61	0,99	0,69	427	147	140
safety device	1,26	0,88	1,64	355	32	29
finger	3,38	0,61	0,43	434	87	43
sensor (for robot)	0,99	1,44	0,71	691	139	84
actuator	1,14	1,00	2,00	346	80	39
Control technology						
positioning control	0,94	1,90	1,35	670	168	94
program control	0,83	2,05	2,19	942	186	137
teaching system	0,96	1,44	3,75	296	22	19
interface	1,03	1,55	0,68	207	56	37
remote control	1,10	2,55	1,86	164	181	60
power assist and wearable	1,50	2,75	1,00	25	30	8
Intelligence technology						
artificial intelligence	0,84	1,39	1,00	367	105	34
control of mobile robot	1,27	1,75	1,58	605	184	98
swarm robot	1,89	2,23	1,14	104	129	60
Communication technology						
image processing	1,06	1,98	1,00	536	152	54
sound recognition	1,04	1,08	0,97	1004	152	71
voice synthesis and interactive technique	1,06	0,61	0,87	611	58	28
communication other than voice and image	1,25	1,06	2,33	115	33	10

Source: JPO (2006)

Note: The technologies shed in yellow correspond to the next generation robot technologies (NGRT), which play a key role in the emergence of the service robot industry.

Table 4: Definition of IPC

IPC 1digit level	Definition
A	HUMAN NECESSITIES
B	PERFORMING OPERATIONS; TRANSPORTING
B25	robot related technologies
C	CHEMISTRY; METALLURGY
E	FIXED CONSTRUCTIONS
F	MECHANICAL ENGINEERING; LIGHTING; HEATING; WEAPONS; BLASTING
G	PHYSICS
H	ELECTRICITY

Source: See the following website for more details: http://www.wipo.int/classifications/ipc/ipc8/

Note: IPC is a international classification of patents from the viewpoint of technologies. Each patent has several kinds of IPCs.

Table 5a: Ranking of the Top Ten Non-NGRT Patent Applicants (1993-2004, absolute numbers)

Players	Industry	Non-NGRT patents	Total patents	Ratios of Non-NGRT (%)
Yaskawa Electric Corporation	R	477	596	80,03
Matsushita Electric Industrial Co. Ltc	EM	466	760	61,32
Fanuc Ltd.	R	341	469	72,71
Toshiba Corporation	EM	280	506	55,34
Sony Corporation	EM	253	1215	20,82
Kawasaki Heavy Industries Ltd.	M	236	314	75,16
Mitsubishi Electric Corporation	EM	214	360	59,44
Hitachi Ltd.	EM	210	386	54,40
Mitsubishi Heavy Industries Ltd.	M	179	424	42,22
Denso Corporation	A-EM	167	330	50,61

Note 1: In this table, we calculate the number of patents considering the overlap across 20 technological fields.

Note 2: The following abbreviations have been used regarding the industries to which the companies belong to: R = robot; EM = electrical machinery; M = machinery; A= automobile industry

Table 5b: Ranking of the Top Ten NGRT Patent Applicants (1993-2004, absolute numbers)

Players	Industry	NGRT patents	Total patents	Ratios of NGRT (%)
Sony Corporation	EM	962	1215	79,18
Honda Motor Co. Ltd.	A	310	368	84,24
Matsushita Electric Industrial Co. Ltc	EM	294	760	38,68
Mitsubishi Heavy Industries Ltd.	M	245	424	57,78
Toshiba Corporation	EM	226	506	44,66
Hitachi Ltd.	EM	176	386	45,60
Denso Corporation	A-EM	163	330	49,39
Toyota Motor Coporation	A	157	321	48,91
NTT corporation	T	147	276	53,26
Mitsubishi Electric Corporation	EM	146	360	40,56

Note 1: In this table, we calculate the number of patents considering the overlap across 20 technological fields.

Note 2: The following abbreviations have been used regarding the industries to which belong the companies: R = robot; EM = electrical machinery; M = machinery; A= automobile industry

Table 6: Ranking of most players according to the average number of claims in case of NGRT patents

firm name	NGRT	non-NGRT	Total number of patent applications	Firm size	Date of foundation
Segatoys	31,2	n.a	8	114	1991
RHYTHM WATCH	20,3	6,0	10	1047	1950
Suruga Seiki	19,5	6,8	9	311	1964
Japan factory automation	17,3	n.a	6	40	n.a
Namco	16,4	n.a	12	891	2006
Tech experts	16,3	11,3	8	21	1996
Sony	15,1	6,8	1215	167900	1946
Navigation network	13,5	n.a	6	n.a	2001
Tokai Rika	13,0	4,1	18	15366	1948
JEOL	13,0	7,1	10	3114	1949
Matsushita Electric Works	11,8	7,7	141	58490	1935
NIPPEI TOYAMA	11,7	5,6	12	640	1945
Seiko Epson	11,6	9,9	128	79914	1942
NEC	11,5	4,7	245	142358	1899
Sharp	11,5	6,7	153	55000	1935
Fuji Xerox	11,3	5,6	24	40228	1962
NTT	10,7	8,4	276	195000	1985
Ricoh	10,2	8,3	166	108500	1936
Shinkawa Electric	10,0	n.a	11	638	1951
Daihen	9,3	5,8	127	3490	1919
CASIO	9,2	9,0	51	12247	1957
Cohnan Engineering	9,0	10,0	8	10	1993
Ueda Japan Radio	9,0	6,5	7	627	1949
Ueno Seiki	9,0	5,0	8	175	1972
Tmsuk	9,0	4,0	45	20	2000
Kawasaki Heavy Industry	8,8	6,9	314	32297	1896
CANON	8,8	8,0	172	18571	1968
Panasonic	8,6	4,5	760	384586	1935
Honda	8,5	6,4	368	176815	1948
Yokogawa Electric	8,5	4,4	20	19574	1920
Hitachi	8,5	6,7	386	359746	1920
Seiryo Engineering	8,5	2,6	12	528	1961
ZMP	8,3	n.a	8	20	2001

Note; firm size is given on a consolidated basis

Table 7: Knowledge flows from non-NGRT patents to NGRT patents

Total number of NGRT patents	NGRT patents with Non-NGRT IPC codes	NGRT patents without Non-NGRT IPC codes
5442	1547	3895

Table 8: Knowledge flows from IPC 1 digit *and 2 digit* level to non-NGRT and NGRT

	Non-NGRT	NGRT
B25	47,73	37,83
A	2,10	15,30
B (except B25)	19,43	6,92
C	0,59	0,07
E	0,29	0,14
F	3,76	1,12
G	10,69	32,62
H	15,42	6,01
Total	100	100
Herfindahl index	0,27	0,18

Table 9a: Shares of collaborative/non collaborative patents for NGRT and non-NGRT patents (1993-2004)

%	Total	Non collaborative	Collaborative	FF	FU	F
NGRT	39	39	43	41	47	38
non-NGRT	61	61	57	59	53	62

Table 9b: Shares of collaborative/non collaborative patents for NGRT and non-NGRT patents (1999-2004)

%	Total	Non collaborative	Collaborative	FF	FU	F
NGRT	50	50	53	52	55	49
non-NGRT	50	50	47	48	45	51

Appendix 1: List of the 19 interviewees (March - December 2006)

Public institutions (7)

- CSTP – JST

- METI

- Ministry of Public Management, Home affairs, Posts and Telecommunications

- NEDO

- AIST – JRL – ISRI

- Kenkyukai

- Fukuoka Prefecture government

Private firms (6)

- Mitsubishi Heavy industries

- Yasukawa

- Toyota

- Yamaguchi robotics institute

- ZMP

- Tmsuk

Universities (3)

- Kyushu Institute of Technology Faculty of Computer Science and Systems Engineering Department of Systems Innovation and Informatics

- Kyushu University, Faculty of Information Science Electrical Engineering, Department of Intelligent Systems, & member of RDIC (Fukuoka)

- Kyushu University, Faculty of Engineering, Departments of Mechanical Engineering Science and Intelligent Machinery and Systems, Control Engineering Lab.

Others (3)

- Robosquare

- JARA

- International Rescue System Institute (NPO)

Appendix 2: Definition and Descriptions of the Service Robot Industry

The definition of the service robot industry is not an easy undertaking since it is an emerging industry. Service robots have no strict internationally accepted definition yet, but are mostly grasped as a subclass of robots, with an additional distinction between personal and professional uses. We thus rely on the preliminary definition of the IFR. Since 2007 a working group of ISO is revising the ISO 8373 which finally will include an official definition of service robots, including service robots for personal use.

In two aspects, the service robot industry is different from the industrial robot industry, and forms as such a new "branch": First, the service robot industry aims at a new market, namely beyond the market of classical industrial robots. The main difference with the former industry is that whatever their use - they may be for personal use or for industrial use - they focus on service rather than on manufacturing. However, since it is a new industry, markets are just emerging and in a very preliminary stage, and there are only few products on the market. Therefore, service robots are presently classified under the category of robots in the industrial classification (app. 3). Examples include robots for families which help for housework (e.g. PaPeRo by NEC), robots for elder people used in medical care and welfare (e.g. My spoon by SECOM), robots for entertainment (e.g. AIBO by Sony) or robots for security (e.g. Guard robot by ALSOK). Second, the service robot industry essentially builds up on new knowledge, the so-called NGRT with different technological capabilities, especially superior mobile functions and image processing functions.

Japan possesses comparative advantages in the service robot industry. Japan is the dominant player in patenting in almost all technological areas, also in service robots (mobile robots, artificial intelligence, controle of mobile robot, image processing, sound recognition). Althought the US became recently active in some service robot-related technologies such as mobile robot and image processing, it is still far from catching up Japan. Finally, Europe is clearly lagging behind. What this table does not tell us is whether the next generation robot technology was historically born in Japan or in the US. Based on the interviews we had with some key actors of the industry (see appendix 1), we know that next generation robot technology emerged almost simultaneously in Japan and in the US. Then, Japan has taken the advantage rapidly. However, the development has been different depending on the uses: for example, the US got an advantage in NGRT applied to military or nuclear plant uses, whereas Japan has an advantage for various uses in service-related fields (compare table 3).

Appendix 3: The robot industry in the industrial classification in Japan

(Source: Statistics Bureau: http://www.stat.go.jp/english/index/seido/sangyo/san07-3a.htm#e)

E MANUFACTURING

09 MANUFACTURE OF FOOD

(…)

23 MANUFACTURE OF NON-FERROUS METALS AND PRODUCTS

24 MANUFACTURE OF FABRICATED METAL PRODUCTS

25 MANUFACTURE OF GENERAL-PURPOSE MACHINERY

26 MANUFACTURE OF PRODUCTION MACHINERY

260 ESTABLISHMENTS ENGAGED IN ADMINISTRATIVE OR ANCILLARY ECONOMIC ACTIVITIES (26 MANUFACTURE OF PRODUCTION MACHINERY)

261 AGRICULTURAL MACHINERY AND EQUIPMENT

262 MACHINERY AND EQUIPMENT FOR CONSTRUCTION AND MINING

263 TEXTILE MACHINERY

264 DAILY LIVES INDUSTRY MACHINERY

265 BASIC MATERIAL INDUSTRY MACHINERY

266 METALWORKING MACHINERY AND ITS EQUIPMENT

267 SEMICONDUCTOR AND FLAT-PANEL DISPLAY MANUFACTURING EQUIPMENT

269 MISCELLANEOUS PRODUCTION MACHINERY AND MACHINE PARTS

2691 Molds and dies, parts and accessories for metal products

2692 Molds and dies, parts and accessories for nonmetal products

2693 Vacuum equipment and vacuum component

2694 Robots

2699 Production machinery and machine parts, n.e.c