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PATENT NETWORKS, COLLABORATION PATTERNS, AND NATIONAL INNOVATION SYSTEMS. SWEDEN AND SPAIN DURING THE SECOND INDUSTRIAL REVOLUTION

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Patent Networks, Collaboration Patterns, and National Innovation Systems. Sweden and Spain during the Second Industrial Revolution[1]

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Abstract:

Sweden and Spain have developed very distinct systems of innovation over the long term. The former has a highly innovative economy while the latter drags serious problems in science and technology. However, during the first half of the nineteenth century both countries were latecomers to the industrial revolution in the European periphery with similar economic, technological, and institutional challenges ahead. In this paper, we hypothesize that one possible reason for this long-term divergence lies in the different collaboration patterns that emerge from interactions among innovative agents. To analyse such cooperation patterns we apply social network analysis methods and study co-patent networks in Sweden and Spain during the second industrial revolution (1878-1914). The results demonstrate that collaboration among innovators and openness to foreign influence was greater in Sweden than in Spain. This research opens new paths for further studies both on economic history and innovation networks dynamics.

JEL: N01, N73, O30, O33, Z13

Key-words: Collaboration, Innovation networks, Patents, Social network analysis, Sweden, Spain, Second Industrial Revolution

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1. Introduction

Traditionally, Nordic countries have been associated with cultural values and attitudes that facilitate higher levels of social cooperation compared to those existing in Latin countries. Several studies provide abundant evidence on such cultural differences across nations and their social and economic implications (see Ronen and Shenkar, 1985; or Hofstede, 2001). For instance, innovation processes and related institutions are firmly based on collaborative interactions among different actors and agents; attitudes that are not complementary elements but rather central factors determining the success of innovation activities in countries and regions (e.g. Allen, 1983; Saxenian, 1994).

Moreover, in countries such as Sweden, cooperative values and collaboration seem to be associated with a greater propensity to establish technology alliances among entrepreneurs (Steensma et al., 2000) and thus to reduce uncertainty and contribute to economic success in the long run. On the other side, in countries such as Spain, the weaknesses and complex social attitudes towards education, innovation, or entrepreneurship –and their effect on the economic activity– still occupies the mind of relevant scholars, such as Luis Garicano[5], who likes to begin his numerous talks on these issues with an economic history dilemma: When did Sweden decide to "become" Sweden and why does Spain still struggle with the same unresolved key institutional and social problems?[6]

Actually, Spain drags serious failures in central points for a developed European economy –such as in the education system or in science and innovation management– since the beginning of the modernization process during the nineteenth century. Around 1830, Sweden and Spain were both peripheral economies at the North and South of Europe that shared similar challenges with other latecomers and developing countries trying to follow Great Britain's industrial and technical success. A hundred and fifty years later, Sweden occupied one the first positions in world economic and social development with great outcomes in such key issues where others had failed: a top higher-education and engineering standards and an efficient design of her system of innovation[7]. In the twenty first century, one of the main Swedish exports is technology and patent licenses[8] while Spain's main commercial assets are sun, tourism, and food and beverages. Since 2010 the Swedish youth unemployment rate has constantly decreased from around 26% in the worst

[5] Professor of Economics and Strategy at the London School of Economics and head of economic policy of *Ciudadanos*, a new Spanish political party.

[6] There are many interviews and opinion pieces insisting on it: see, for instance, Garicano (2016) or Hernández (2015).

[7] Some key indices where Sweden perform high are *The Global Competitiveness Report* from the World Economic Forum (Schwab and Sala-i-Martín, 2016). Sweden ranks 6th (institutions 4, macroeconomic environment 5, technological readiness 4, innovation 6), while Spain ranks 32nd (institutions 55, macroeconomic environment 86, technological readiness 25, Innovation 38). Other examples include the Global Innovation Index (2016) where Sweden ranks 2nd and Spain 28th. According to data from WIPO, during 1980-2015 Sweden has averaged more than 500 residents patent applications per million population, while the same number for Spain is around 70 (WIPO statistics database 2016).

[8] In 2015 Sweden had a net intellectual property trade of $4.7 bn, while the respective trade for Spain were negative with $2.9 bn (IMF 2015).

moments of the 2008 crisis to a current 17% (and practically is non-existing among young Swedish nationals)[9] while youth unemployment in Spain was around 50% in 2011 and thousands of recent graduate Spanish technicians, scientists, engineers, o physicians are leaving the country.

Therefore, although Spain and Sweden were relative latecomers to the industrial revolution, from 1880 onwards Sweden was able to develop an advanced system of innovation based on core R&D capacities and efficient related institutions that have boosted its economy in the long run, while Spain deepened its technological and scientific dependence and backwardness that acts as an Achilles heel during economic contractions. Certainly, the causes of such distinct evolution may be very complex but it is a common opinion that they are mainly related to institutional arrangements, political issues, and social phenomena, difficult aspects to internalize in economic analysis.[10] We do not attempt to completely disentangle all those causes but to contribute to the historical understanding of some of the more significant. More specifically, in this paper we aim to gain insights into the origins and configuration of the "national innovation systems", i.e. "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman, 1987, p. 1). Among all the topics that this concept covers, we focus on the networks of inventive and entrepreneurial activity that can be traced through the study of the Swedish and Spanish patent systems.

Over the last decades, a growing body of research has analysed the dynamics of such innovation networks and their influence on firms and regions (see Pippel, 2012 or ; Phelps et al., 2012 for recent reviews). According to this literature, networks are crucial for innovation as they encourage the cross-fertilization of ideas among the involved partners, provide access to external knowledge and specialized labour force, allow the sharing of costs for innovative projects, reduce opportunistic behaviours, contribute to the division of labour, and may result in a higher market diversification of firms (Nelson and Winter, 1982; Katz and Martin, 1997; Hagedoorn, 2002). Part of this research use the term network as a metaphor referring to the interactions among innovators (de Faria et al., 2010; Almeida et al., 2011). Other studies follow a more analytic approach and consider networks as sets of nodes, identifying the actors, and links, representing collaborative interactions among them (Ahuja, 2000; Fleming et al., 2007; Schilling and Phelps, 2007; Breschi and Lissoni, 2009; e.g. Whittington et al., 2009). Using theoretical frameworks and analytical tools taken from social network analysis (SNA), these later studies have been able to measure social structures of collaboration and to identify different network topological properties that can influence innovation processes positively. Furthermore, recent research on patent networks highlights how such connections among actors, from the same but also from distinct technological fields and expertise, are key issues for future innovation paths and rhythms

[9] Among people with post high-school education the unemployment rate in Sweden was 4.4 % in 2016. Furthermore, the youth unemployment (ages 15-24) in Sweden includes full-time students that has reported that they are looking for extra or part-time jobs. The unemployment rate of youths not studying was 6.5% in 2016. Source: Arbetskraftundersökningarna, Statistics Sweden.

[10] Luis Garicano and Antonio Roldán (2015) titled the Introduction of their book about Spanish failures with respect to Sweden and other Northern democracies as follows: "To invest in people, institutions, and principles for a new economic model."

(Acemoglu et al., 2016). These findings may imply that cuts in R&D investments in particular areas or bad configurations of collaboration networks would not only impact in current economic performance but would affect the whole system of innovation in the long run.

Notwithstanding, all this research effort has focused on relatively recent periods (from 1975 onwards) and, therefore, on already established innovation systems. As far as we are aware, there are no historical and long-term studies analysing how innovation networks first arose, how collaborative patterns developed, how they evolved, and what it meant for the economic and historical dynamics of the national innovation systems in which they emerged. The purpose of this work is to answer these questions by comparing the structures of collaboration involved in the innovation processes of Spain and Sweden during the Second Industrial Revolution (1878-1914), a key period for world economic history in general and for the distinct development paths taken by these two countries in particular.

For this reason, we have constructed two new historical data sets on patentees operating in Spain and Sweden during this period. Thus, we use patents as a proxy to identify connections among innovators and to measure structural network patterns (closeness, density, clustering rates, large components, etc.) in order to determine the level of collaboration and to assess their possible effect on Spanish and Swedish innovation processes. Given that collaboration among inventors and entrepreneurs is a key issue for the success of innovative activities we test the hypothesis that there had to be significant differences between patentee networks in Sweden and Spain, that may help to explain the distinct paths taken in the organization of their patent institutions and systems of innovation, which in turn influence future economic and technological development.

The rest of the paper is organized as follows: Section 2 analyses the origin and characteristics of the Swedish and Spanish patent institutions during the period studied; Section 3 deals with methodological issues related to patent data and especially to SNA tools and indicators; Section 4 provides our first results on the network comparison; and Section 5 concludes and gives suggestions for future research.

2. Patent institutions and the Spanish and Swedish innovation systems

The British industrial revolution set in motion a radical change in human history. Technology, science, and innovation progressively turned into key issues for the new economic paradigm. During the nineteenth century, countries from distinct geographical, economical, historical, and cultural backgrounds followed this new path and converged in an attempt to industrialize, from western and eastern Europe to millenary Japan and the younger nations in America or Australia. With distinct rhythms, circumstances, and positions, many countries joined the club of industrial capitalism that lead to a first wave of economic and commercial globalization before WW I.

Despite this convergence process, technological, political and institutional differences still contributed to distinct growth and development levels reached by pioneers and first followers with respect to latecomers or developing economies throughout the world. In the old Europe, countries such as Spain or Sweden occupied peripheral economic and technological positions at the beginning of the nineteenth century, each one with different populations, resources, climates, and historical backgrounds but with similar institutional challenges in order to encourage capitalism and industrialization. Moreover, throughout the nineteenth century both countries undertook a general institutional change that gave shape –among other things– to their "systems of innovation", i.e. the constellation of public and private agents, institutions, firms, education and scientific policies, entrepreneurship attitudes, and social and cultural factors that altogether co-evolve and determine the scale and scope of innovation processes and technological change in the long run (Freeman, 1987; Lundvall, 1992; Nelson, 1993).

Interestingly, from a common starting point at the beginning of the nineteenth century, the Swedish and the Spanish innovation systems reached radically different results during the twentieth. The former achieved an outstanding success in using technology, innovation, science, and education as a driving force of long-term economic and social development. The latter was more close to a general failure on the same issues, depending on foreign technological and scientific activity. Undoubtedly, many factors may contribute to explain such divergent evolution. However, in this section we will focus our attention on one of the more significant parts of national innovation systems: the establishment and functioning of intellectual property regimes, mainly patent systems, designed to foster inventive activity and promote industrial advance.

A patent is a contract between the creators of new inventions with industrial application and the society. Patentees obtain a temporary monopoly for the use of their inventions in exchange of detailed descriptions of them, which allows others to build on the new knowledge that will be freely available to the public when the patent term ends. Patents can furthermore be applied for individually or by several persons and/or firms reflecting relationships among inventors and entrepreneurs collaborating in the pursuit of a monopoly right. Such relationships may reflect inventors working together or alliances with capitalists for creating a firm, or even collaboration among innovative companies.

Patents are not a perfect proxy for measuring innovation, as innovation may also be the result of non-registered inventions, technology transfers or organizational know-how difficult to protect (Griliches, 1990). On the other hand, a significant percentage of registered patents are never used and, therefore, do not produce actual innovations. Notwithstanding, patents have significant advantages over other proxies especially for long-term studies: patents are available in many countries from the first half of the nineteenth century making it possible to create reliable historical time-series; they can be used as a partial technological indicator for measuring technological opportunity, impact, and capacity (Andersen, 2001, chap. 2) and, at any rate, they are a good proxy for measuring investments in new technologies within a specific economy independently of their final success (as generally occurs with capital investments).

Great Britain passed a first patent statute in 1624, the United States did it in 1790, and France in 1791. Sweden and Spain were among the firsts in enacting modern patent laws during the first half of the nineteenth, in 1819 and 1820 respectively. Table 1 shows that the evolution of patent legislation in both countries had common points but also outstanding differences as time went by. They initiated their modernization process passing basic patent systems designed to incentive innovation, but especially to foster industrialization and, therefore, not fully recognizing IPRs to original inventors. Both had "patents of introduction", which allowed registering others' inventions for a short period of time if such new ideas were not used and in practice within the country. In order to favor domestic manufacturing, both countries established compulsory working clauses as a requirement to maintain the monopoly during the patent term. However, from mid-nineteenth century, and especially from 1884 onwards, the Swedish patent system began to converge with stronger patent institutions. Patents of introduction were avoided in 1856 and compulsory working clauses in 1902. Spain retained both issues until her entry in the European Union in 1986.

The Spanish patent regime was always based on a simple registration system, with neither previous technical exams nor opposition proceedings. Specifications and drawings were not openly published and there never was any specific patent jurisdiction. On contrary the Swedish system evolved from such a registration system, with calls for oppositions since 1856, to the establishment of hard previous technical and novelty exams in 1884 in order to reject obvious and low-value inventions. Only the United States in 1836 and Germany in 1877 had previously introduced such kind of exams. Besides, Sweden published complete patent specifications since 1856, established a specific patent jurisdiction and court in 1884, and patent fees were seven times cheaper than in Spain during most of the period analyzed. This long-term institutional evolution clearly points towards a significant shift in the quality and achievements of the Swedish innovation system, especially from the Second Industrial Revolution onwards, that apparently, Spain was not able to reach. Sweden evolved to protect original invention activity and to reinforce IPRs, which we argue had to be related to increasing competences in innovation and technological development.

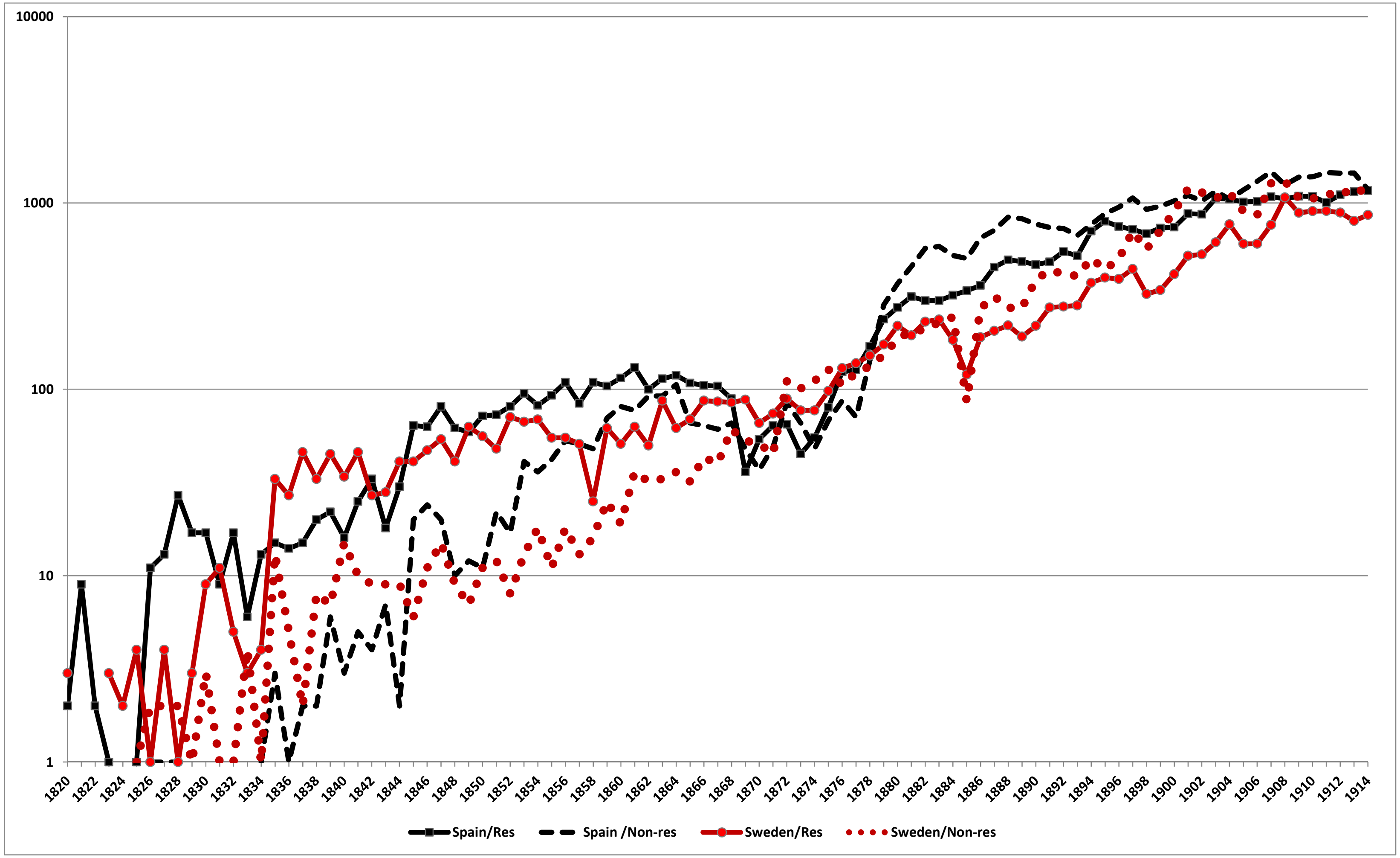
Table 1: Patent institutions in Spain and Sweden, 1800-1914

	SPAIN	SWEDEN
First Patent Law	1811-1820-1826[(1)]	1819
Subsequent Laws until 1914	1878, 1902	1834, 1856, 1884
Member of the International Union for the Protection of Industrial Property	From 1884	From 1885
Previous novelty and technical exams	No	From 1885
Opposition proceedings	No	-From 1819 to 1834 within 2 months -From 1835 to 1856 six months -From 1885 two months
Priority rights to previous foreign patents	-From 1878 two years[(2)] -From 1884 one year[(2)]	-From 1856 indefinite for the original inventor[(2)] -From 1885 one year[(2)]
Patent term	-5, 10 or 15 y. before 1878[(3)] -20 y. from 1878	-5, 10 or 15 y. before 1856[(3)] -3 to 15 y. between 1856 and 1884[(3)] -15 y. from 1885
Patent extension possibility beyond the maximum term	No[(4)]	No[(4)]
Payment system	-In advance before 1878 -Annual progressive installments from 1878	-In advance before 1884 -Annual progressive installments from 1885
Fees for a full-term patent	-Before 1878: 1,500 pts. -From 1878: 10 pts. for the first installment and a total of 2,100 pts. paid for a 20 y. patent	-Before 1885: 144 crowns -From 1885: 50 crowns for the first installment and a total of 775 crowns for a 15 y. patent
Fees in 1876 British pounds	-Before 1878: 60 p. -After 1878: 0,4 p. for the first installment and a total of 84 p. for a 20 y. patent	-Before 1885: 8 p. -After 1884: 2,8 p. for the first installment and a total of 43,1 p. for a 15 y. patent
Patents of addition	From 1878[(5)]	From 1885[(5)]
Patents of introduction	Yes (5 y.)	Until 1856 (for 5 y.)[(6)]
Compulsory working clauses	-Within 1 year before 1878 -Within 2 years from 1878 to 1902 -Within 3 years after 1902	- Within 1-4 years before 1885 -Within 3-4 years from 1885 to 1902
Compulsory licenses	No	From 1902[(7)]
Importation prevention	Yes[(8)]	Yes
Publication of patent specifications / drawings	No[(9)]	From 1834 detailed specifications
Specific patent jurisdiction	No	From 1885

(1) The law of 1811 was enacted during the French occupation (1808-1814); the first Spanish law was enacted during the period 1820-1823; and eventually in 1826.
(2) In Sweden, from 1856 original inventors with previous foreign patents can apply for a patent that never could last more than the original one. In Spain, from 1878 to 1884 foreign patents claiming priority rights had two years but limiting the patent term to 10 years. From 1884 in Spain and 1885 in Sweden there was one year of priority rights according to the *International Union for the Protection of Industrial Property*.
(3) In Sweden, between 1819 and 1884 the applicant could indicate a desired patent term but it was determined by the Department of Commerce on basis of the novelty and usefulness of the invention. In Spain, before 1878 the applicant decided the patent term (5, 10 or 15 years).
(4) In Sweden, after 1884 patents that had expired before the 15-year limit could be revived at a later date, under special circumstances. In Spain, before 1878, 5-year and 10-year patents of invention could be extended until 15 years.
(5) In Sweden, between 1835 and 1885 improvements to older inventions were treated as a separate category and were limited to 10 years. In Spain, before 1878 any improvement was treated as a new application.
(6) In specific cases they could be granted for 10 years depending on the difficulties to introduce the foreign invention.
(7) After 1902, if the patent was not working within Sweden competitors could apply for compulsory licenses in the courts.
(8) Patents of introduction cannot block importations.
(9) Even after 1886 (International Agreements) only patent titles and owners were published (never specifications or drawings).

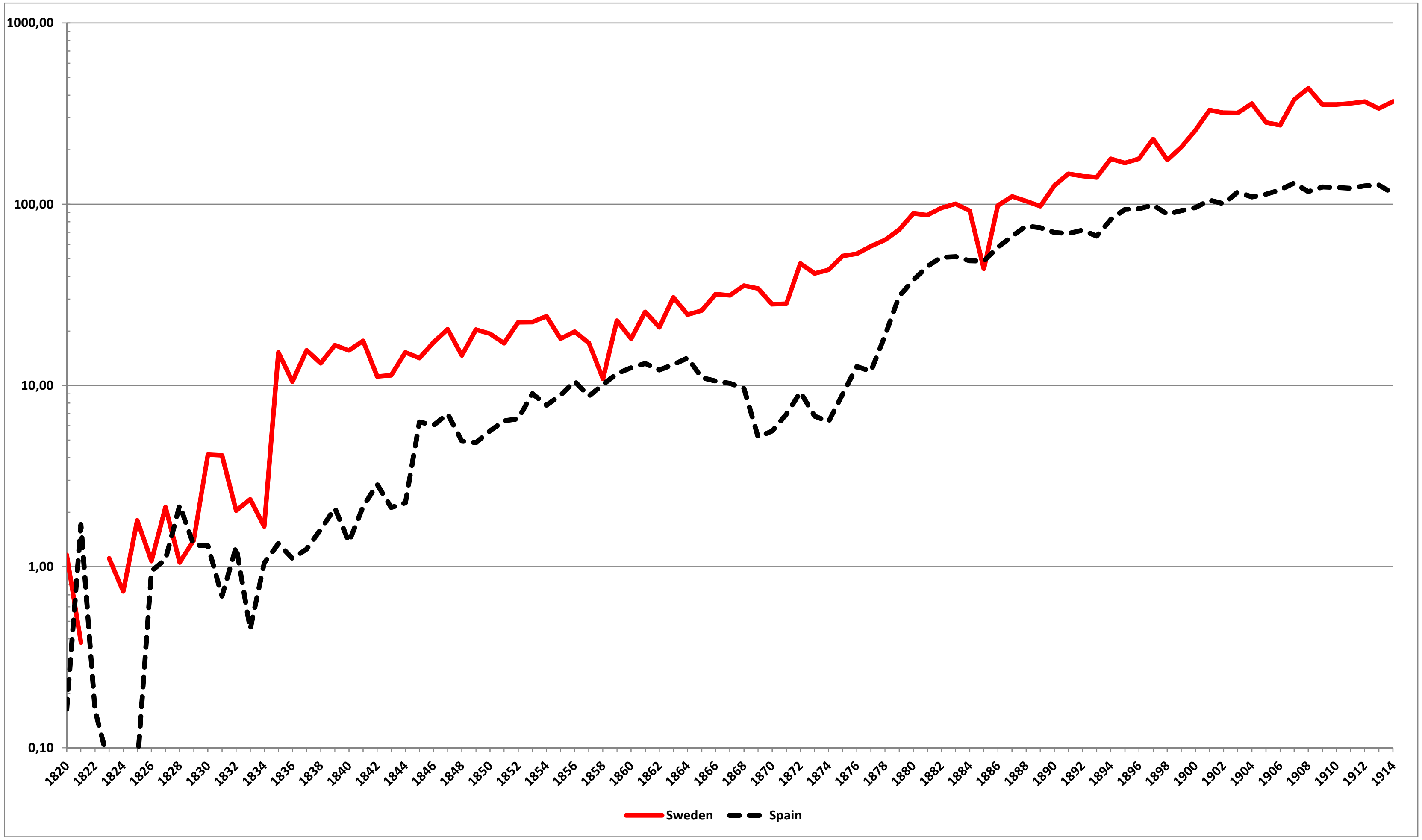
Source: Andersson (2016) and Sáiz (2002)

Figure 1: Total registered patents in Spain and Sweden, 1820-1914.



Source: Sáiz et al. (2000 onwards) and Andersson (2016).

Figure 2: Patents per million inhabitants in Spain and Sweden, 1820-1914



Source: Patents: see Figure 1; Statistics Sweden (2017) and Mitchel (1975).

Figure 1 depicts the evolution of foreign and domestic patents in Spain and Sweden during the period studied and clearly reveals two distinct phases. The first, from the beginning of the nineteenth century to the late 1870s, shows low-level patent activity (under 200 patents per year) dominated by resident patentees in both countries. It corresponds to the period of general institutional and economic change in order to foster industrialization and based in the aforementioned simple registration systems. During the second phase, from 1880 to 1914, a major shift took place with an outstanding increase in patenting (between 1,000 and 2,500 patents per year in each country) now driven by foreign applications. Although domestic patents also increased notably in Spain and Sweden, non-resident invention activity flooded both countries, revealing an international integration related to the Second Industrial Revolution and the first technological globalization. As we have stated, during this second stage the Swedish patent system evolved to match the world leading IPR practices while the Spanish remained within the old parameters.

At any rate, Figure 1 shows a similar general tendency in patenting in Spain and Sweden that –apart from specific events that affected each patent series, such as, for instance, the crucial impact of the 1864 financial and 1868 political crisis in Spain– does not provide major evidence to explain structural changes in their national innovation systems beyond the institutional evolution showed in Table 1. All in all, although Spain granted more patents than Sweden during the period studied (in which the absence of previous technical exams with respect to post-1884 Sweden undoubtedly influenced), a simple control by population (Figure 2) reveals a stronger propensity to patent in the latter with respect to its market size. In patents per million inhabitants, Sweden was far from Spain especially from 1834 onwards,[11] which reveals a higher "innovation density" in the Swedish society that may increase the possibility of interaction among agents.

Notwithstanding, if we analyze the basic patterns of co-patenting and patentees' registering behavior in Spain and Sweden (Table 2) there is no radical difference. In both countries, the majority of patents were granted to just one applicant (approximately 89%) and the rest to two or three, which suggests a very basic and limited collaboration among innovators during the nineteenth century. In Spain or Sweden just 0.24% of the patents had more than three applicants (and never more than six). Similarly, in both countries the majority of patentees applied for just one single patent (approximately 72%); while another 22-24% were involved in two to four patents. Persistent practitioners with five or more patents were scarce although slightly more relevant in the Swedish case (5,23%) than in the Spanish (4,69%).

[11] The propensity to patent may be influenced by lower patent fees in Sweden during most of the century.

Table 2: Patentees per patent and patents per patentee in Spain and Sweden, 1878-1914

	Spain	Sweden		Spain	Sweden
Patentees per patent	%	%	*Patents per patentee*	%	%
6	0.02	0.03	*> 50*	0.03	0.07
5	0.03	0.05	*21 to 50*	0.17	0.22
4	0.19	0.16	*11 to 20*	0.61	0.82
3	1.31	1.16	*5 to 10*	3.88	4.12
2	9.39	10.25	*2 to 4*	24.04	21.91
1	89.05	88.35	*1*	71.25	72.86
Total Patents	***59,537***	***40,923***	*Total Patentees*	***39,109***	***26,058***

Source: See Figure 1.

To sum up, the basic picture of the Spanish and the Swedish patent systems did not differ in basic statistics during the period analyzed, except the aforementioned patent per capita ratios. The most significant difference was the institutional evolution from mid-nineteenth century and especially from the 1880s onwards. During this period, Sweden redesigned her patent system aligning it with the most innovative countries of the time such as the United States and Germany or the United Kingdom. This strongly suggests improvements in the Swedish innovation system and, generally, shifts in the technological capacity of the Swedish economy and society that did not occur in Spain. Nonetheless, more evidence is needed. Thus, throughout the next sections we will use SNA methods to analyze the patent data aiming to find out what can be learned from the study of collaboration patterns in the emerging networks of inventors, entrepreneurs, and innovators in both countries.

3. Patent data and SNA methodology

As stated above, patents and innovations are not synonyms. However, as an investment proxy, patents reflect collaboration among actors pursuing commercial benefits from possible innovations independently of the final results. Hence, scholars have extensively used patents for economic and historical research, which is also true for SNA studies. In this paper, we use two patent data sets for Spain and Sweden, constructed throughout the last decades directly from archival sources. For our purpose, we have extracted all patents registered in both countries between 1878 and 1914, i.e. during the so-called Second Industrial Revolution until WW I.[12] The previous section showed how patent institutions can differ among countries. Although the existence of previous patent examinations and distinct patent terms or costs may influence the propensity to register or the final technical value of the patent, such difference do not essentially affect what we want to analyze: the

[12] The databases contain in total 59,537 patents registered in Spain and 40,923 registered in Sweden between 1878 and 1914. See Sáiz et al. (2000 onwards) and Andersson (2016) for further information.

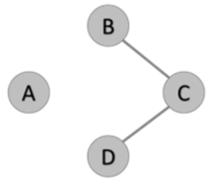
collaboration patterns among patentees. Thus, following recent literature on patents and SNA (Breschi and Lissoni, 2004; Cantner and Graf, 2006; Lobo and Strumsky, 2008; Ter Wal and Boschma, 2009), we use these data sets to trace and depict links among patent applicants in Spain and Sweden during this early key period.

In order to establish the geographical boundaries of the two networks, we only consider patents with at least one applicant residing in the respective country (Spain or Sweden). Patents from non-residents are also important and may facilitate innovation processes, but since we focus on domestic collaboration patterns we restrict the analysis to resident applications. Therefore, the actors or nodes of the networks we are going to construct are patent applicants, most of them individuals but also firms. From this point onwards, we will refer to them generally as innovators. Notice that there can be nodes in the networks located in other countries, i.e foreign innovators cooperating with at least one inventor or entrepreneur inside Sweden or Spain. Hence, we can classify nodes on each network in two categories: resident and non-resident nodes. To draw the links connecting them, we focus on co-patents and assume that two innovators are connected if they have applied for a patent together.

Figure 3 presents an example of a simple network elaborated with basic patent data. Suppose we have only three patents and four patentees. Innovator A holds patent 1; B and C share the property right of patent 2; and C and D hold patent 3. In such a network, we assume that A does not cooperate with any other actor and therefore it appears as an isolate node (i.e. a node without any link; see Figure 3). We also consider that B and C have cooperated to obtain patent 2 and, therefore, we trace a link between them. Analogously, we assume there is a cooperation link connecting innovators C and D, as they both hold patent 3. In summary, the resulting network presents four nodes and two links among them.

Figure 3: An example of patent data and the resulting collaboration network

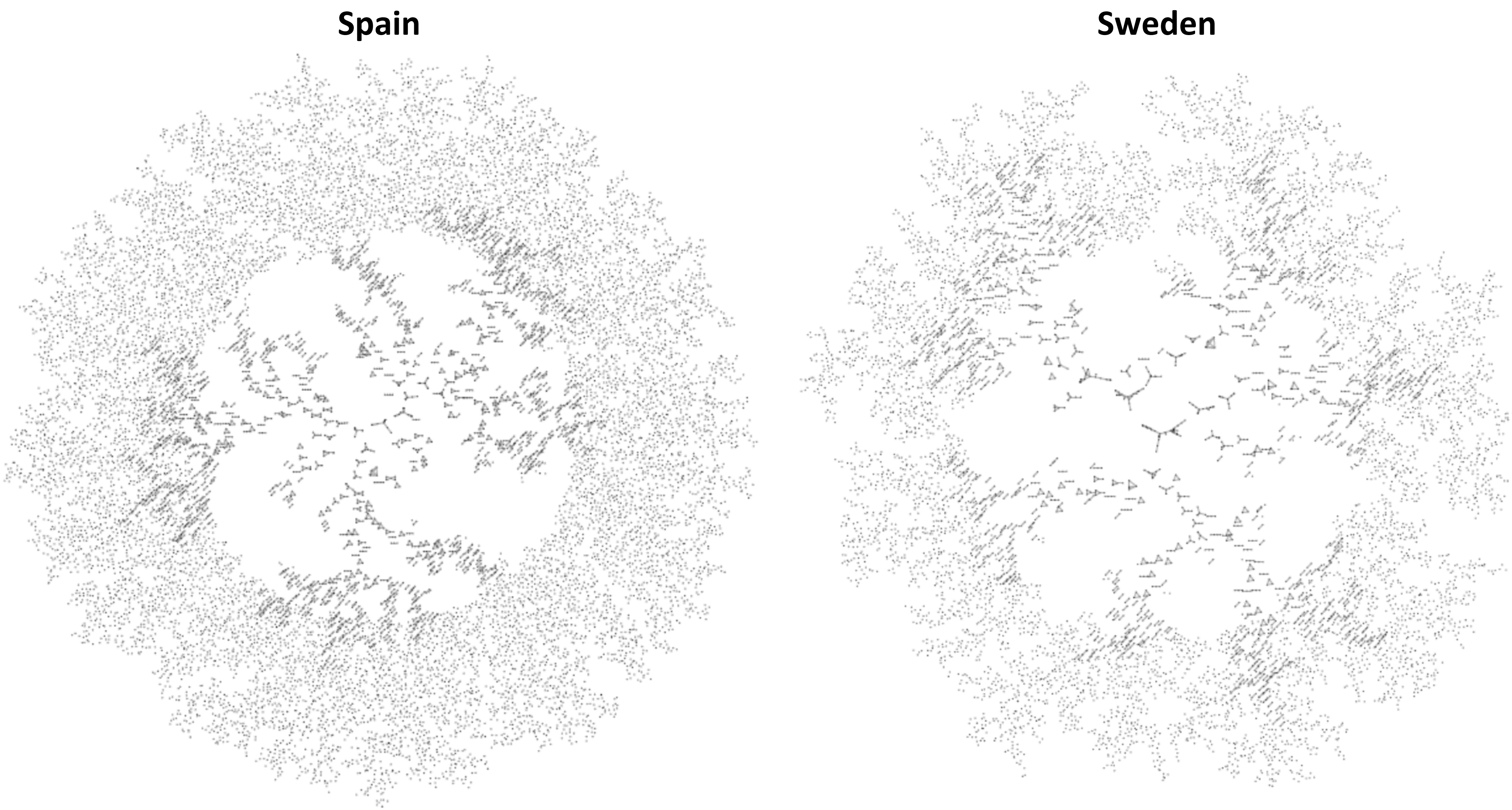
Patent	Innovator
1	A
2	B, C
3	C, D



Hence, each link represents a cooperative relationship between two different innovators. According to the literature on innovation networks, these links allow the diffusion of knowledge that may increase innovative and entrepreneurial capacity of the actors. The overall structure of the network is essential to understand how collaboration patterns may facilitate (or restrict) knowledge diffusion inside the whole system. For example, according to the network topology presented in Figure 3, an idea, can flow from B to C and, later on, to D, while it may not reach A.

We apply this methodology to the Spanish and Swedish historical patent data, obtaining their first patent networks. To study the evolution of the networks, we divide the period of analysis into three stages of twelve years (1878-1889, 1890-1901 and 1902-1914) and draw one network for each one. Additionally, we also calculate the cumulative networks in both countries for the complete period of our research. According to Breschi and Lissoni (2005), the cumulative network describes the ever growing underlying interactions that potentially functions as a network through which relevant innovation related knowledge flows. In conclusion, we draw four different networks for each country: one for each of the three sub-periods established and one cumulative network for the whole period studied.

Figure 4: The Spanish and Swedish emerging patent networks, 1878-1914



Sources: Patents registered in Spain and Sweden between 1878 and 1914 with at least one resident applicant (see Figure 1).

After drawing the networks (Figure 4), we analyse their structural properties, observe their evolution, and compare the results obtained for Spain and Sweden. In doing so, we calculate several indicators that have been used extensively in SNA literature to describe the overall topology of the interactions. First, we analyse two basic network indicators such as the number of nodes and the number of links, which offers a first picture of the network size and level of interaction among innovators. Second, we focus on network connectivity indicators. By network connectivity we refer to the extent to which the nodes are linked to one another and constitute connected components (i.e. groups of nodes in which each pair of them is directly or indirectly connected to each other, but disconnected from the rest of the network).

Previous research has found clear evidence regarding the influence of network connectivity on innovation. According to this literature, connectivity has positive impacts on information access, making it easier and more reliable as more links imply more sources of knowledge and fewer intermediaries (Burt, 2000; Schilling and Phelps, 2007; Whittington et al., 2009; Fritsch and Kauffeld-Monz, 2010). Secondly, network connectivity reduce the possibility of free-riding behaviours, facilitating trust between nodes and leading to collaborative solutions for innovation (Ahuja, 2000; Uzzi and Spiro, 2005; Schilling and Phelps, 2007; Cowan and Jonard, 2008). Finally, studies report a positive association between the formation of large connected components and innovation results (Bettencourt et al., 2007; Fleming et al., 2007; Breschi and Lenzi, 2015). The argument for this is that the interconnection of nodes in large components enhances information flows, knowledge spill-overs, and cross-disciplinary fertilization among a large number of innovators. On contrary, in networks with smaller and isolated groups new ideas remain unknown for the vast majority of actors, opportunities remain unexploited, and innovation is constrained (Fleming et al., 2007).

To effectively measure connectivity, we analyse the number of connected nodes (i.e. those with at least one link) and observe their proportion over the total number of nodes in the networks. After this, we calculate the network density (i.e. the proportion of actual links over the maximum possible number of links given the number of nodes in the network). Comparing density in social networks with different sizes is problematic since the maximum number of links grows geometrically with the number of nodes while the actual number of links usually does not, as actors are usually constrained in terms of time and resources to establish and maintain connections to others (Cantner and Graf, 2006). To face this problem, we calculate the "average degree" (i.e. the average number of links per node), which allows us to compare networks of different size (as is the case for Spain and Sweden). We also analyse the size of the three largest components and an indicator of network aggregation, which is a Herfindahl index of the distribution of the sizes of the different components.[13] A high value of this aggregation index indicates that a great proportion of innovators are grouped into a few large components with fewer actors as isolated nodes.

[13] See Lobo and Strumsky (2008) for more details on this indicator.

Finally, we are interested in how open the networks are to foreign innovators. Several studies on geographically bounded networks have reported that external connections to actors located outside the studied territory are positively associated with innovation results (Fleming et al., 2007; Lobo and Strumsky, 2008; Whittington et al., 2009; Breschi and Lenzi, 2016). This literature states that external links connecting nodes located in other territories can infuse the local community with novel ideas, serving as channels for new and non-redundant information (Lobo and Strumsky, 2008) and providing valuable resources and information advantages that may not be available to local nodes otherwise (Breschi and Lenzi, 2016). Also, external links mitigate the possibility that the knowledge base of local industries might become stagnant (Whittington et al., 2009). Therefore, network openness to foreign actors enhances knowledge creation and fosters innovation.

To measure network openness, we analyse the number of non-resident nodes and their proportion over the total number of nodes in the networks of Spain and Sweden. These measures give us a first picture of the presence of external links in the respective networks. We are also interested in the extent to which non-resident innovators interact with other nodes in the networks and their potential influence over local actors. With this in mind, we calculate the "average degree" and "betweenness centrality" of non-resident nodes, two measures that describe each innovator's prominence or relative importance in the networks. Degree measures the number of links connecting each node, while betweenness focuses on the number of geodesics going through each node (where geodesics are the shortest paths connecting every pair of nodes in the network). Finally, we calculate the total number of local nodes reachable from non-resident actors, both through direct links or through indirect paths. These local innovators are the members of the network that may be potentially influenced by non-resident actors, therefore we refer to this measure as non-resident influence (NR influence).

4. Results: innovation networks and collaboration patterns

Table 3 summarizes the results of our analysis. As expected, the Spanish network is greater in extension –measured by absolute number of nodes– during the three periods studied, although if we take into account the population and market size (see Figure 2) innovators were undoubtedly more active in Sweden. Regarding the evolution of the networks, SNA results show that although the number of nodes grew significantly in both countries, the process was much faster in Sweden, which reveals a greater dynamism in the participation of new innovators than in Spain. The number of links was also higher in Spain during the first two periods. However, this situation changed in the last one (1902-1914), when the Swedish network increased its links and surpassed the level of the Spanish one. This result is the first sign of how Sweden evolved towards a more collaborative structure, which also had significant implications on network connectivity.

Indeed, connectivity indicators reveal two facts. First, these emerging networks were very sparse compared to more recent ones (see Figure 4); and second, the Swedish network is clearly more connected than the Spanish. As per the first conclusion, the indicators show that both networks are very fragmented and disconnected, with a vast majority of innovators acting as isolate nodes (i.e. without any link). According to König et al (2011), this is one of the main stylized facts characterizing this kind of networks today. However, when compared to recent or current patent networks our results reveal that the historical Swedish and Spanish networks were considerably less connected, as corresponds to emerging innovation systems.[14]

Similarly, the low level of connectivity is revealed by the lack of a giant component (i.e. a component agglomerating a significant proportion of nodes) in both countries. Even in the aggregated networks (1878-1914) the largest components in Spain and Sweden had only 17 and 38 nodes respectively. The literature on network evolution states that there is a tipping point on the formation process of a giant component. Before this point, the network is highly fragmented, made of isolate nodes and small components. After the tipping point, a giant component emerges abruptly connecting a significant part of the nodes in the network (Fleming et al., 2007; Casper, 2007). According to our results, we conclude that both networks studied herein were still in an emerging stage before the mentioned tipping point.

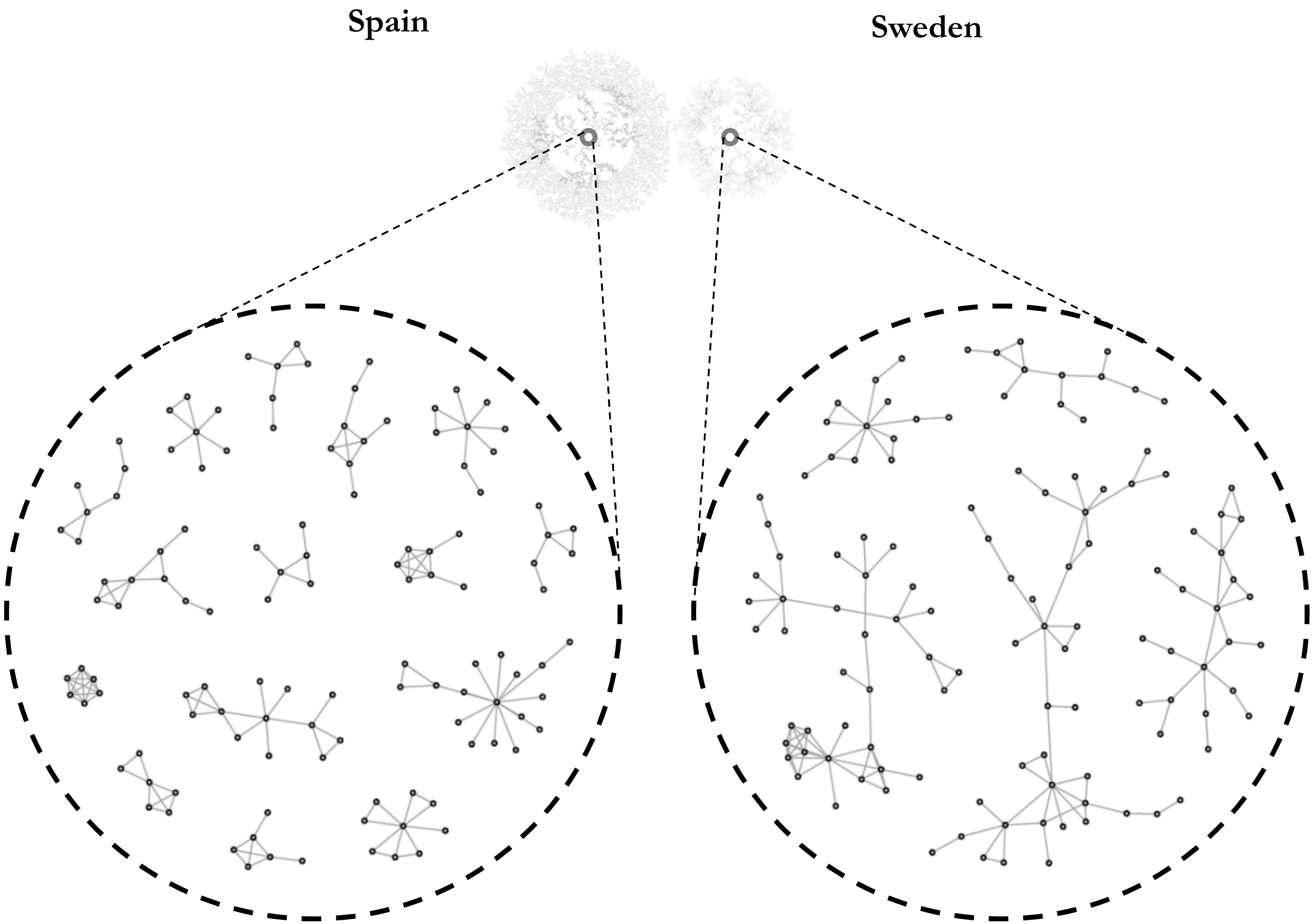
[14] For example, similar studies focused on more recent periods report density values ranging from 0.01 to 0.05 (Cantner and Graf, 2006; Fleming et al., 2007; Lobo and Strumsky, 2008), while in the historical networks that we analyze density ranges from 0.000008 to 0.00004.

Table 3: Patent network indicators in Spain and Sweden

	1878-1889		1890-1901		1902-1914		Cumulative network (1878-1914)	
	Spain	**Sweden**	**Spain**	**Sweden**	**Spain**	**Sweden**	**Spain**	**Sweden**
Number of nodes	2,754	1,571	5,231	2,758	8,308	5,698	14,622	8,866
Number of links	328	207	641	362	941	983	1,879	1,523
Network Connectivity								
Connected nodes								
# of nodes	538	314	1,034	593	1,445	1,457	2,901	2,238
%	*19.54*	*19.99*	*19.77*	*21.50*	*17.39*	*25.57*	*19.84*	*25.24*
Density (x10exp5)	4.33	8.39	2.34	4.76	1.36	3.03	0.88	1.94
Average degree	0.24	0.26	0.25	0.26	0.23	0.35	0.26	0.34
Largest component size								
# of nodes	4	6	7	5	15	19	17	38
%	*0.15*	*0.38*	*0.13*	*0.18*	*0.18*	*0.33*	*0.12*	*0.43*
3 Largest components								
# of nodes	12	17	20	15	32	48	39	81
%	*0.44*	*1.08*	*0.38*	*0.54*	*0.39*	*0.84*	*0.27*	*0.91*
NW aggregation (x10exp4)	4.54	8.30	2.45	4.75	1.55	2.79	0.91	1.95
Network Openness								
Non residents (NR)								
# of nodes	3	29	14	18	18	23	33	66
% of total nodes	*0.11*	*1.85*	*0.27*	*0.65*	*0.22*	*0.40*	*0.23*	*0.74*
NR av. Degree	1.00	1.38	1.07	1.33	1.61	1.39	1.39	1.44
NR av. Betweenness	0.00	0.00	0.00	0.06	0.00	0.09	0.00	0.09
NR influence								
# of nodes	3	31	14	21	30	34	47	129
% of resident nodes	*0.11*	*2.01*	*0.27*	*0.77*	*0.36*	*0.60*	*0.32*	*1.48*
% of connected nodes	*0.56*	*9.87*	*1.35*	*3.54*	*2.08*	*2.33*	*1.62*	*5.76*

Sources: See Figure 4.

Figure 5: Patent network aggregation in large components



The grey networks above are the total/cumulative networks in Spain and Sweden and keep the same proportion of their respective number of nodes (14,622 nodes in Spain and 8,866 in Sweden). The dotted-line circles below show two extracts of the whole networks in Spain and Sweden. In order to facilitate visual comparability, each extract is made of a similar number of nodes (122 in Spain and 121 in Sweden), containing the largest components in the respective national networks. This exercise illustrates how the Swedish network is far more aggregated in large components than the Spanish one: in Sweden, where the total network is significantly smaller, we observe only five components of size 38, 22, 21, 15 and 13 nodes; meanwhile, in Spain, with a larger total network, nodes are aggregated in 15 separate groups of smaller size (17, 13, 9, 8, 7 and 6). All these results lead us to conclude that the network in Sweden could be closer to the tipping point where a giant component emerges.

Sources: See Figure 4.

Despite the fact that both networks were very sparse and fragmented, the results reveal that the Swedish was clearly more connected than the Spanish one. This is confirmed by all the connectivity indicators we use. For instance, we observe that the proportion of connected nodes was greater in Sweden than in Spain during the three periods studied (and during the last period it was also greater in absolute number of connected innovators). Between 1902 and 1914, more than 25% of Swedish innovators collaborated with at least other actor while in Spain only 17.4% of them did.

The density indicator in Sweden doubles the Spanish one. As per the average degree, both countries register similar results during the first two periods (with Sweden slightly above); however, during the third period the average number of collaborative links among Swedish innovators increased considerably reaching up to 0.35 while in Spain decreased to 0.23. This evolution affected considerably the structure of the cumulative networks where the Swedish average number of links per node was 25% higher than the Spanish.

Furthermore, the Swedish network had a greater proportion of large components with respect to the Spanish one; larger even in absolute terms in some of the periods studied as well as in the cumulative network (see Figure 5). Similarly, the aggregation index in Sweden almost doubled that of Spain, showing how collaboration links in the former country constituted larger groups of innovators that could facilitate and accelerate the diffusion of ideas. A greater level of aggregation can also indicate that the Swedish network was closer to the tipping point when a giant component emerges (usually from the union of separated large components).

Finally, indicators for network openness to non-resident actors (NR) tell us a similar story. First, we observe that both in Spain and Sweden innovators residing abroad but linked to resident inventors and entrepreneurs represented only a tiny fraction of all actors in the patent networks. Thus, this shows that both networks were generally closed to interactions with NR actors. However, as in the case of connectivity, all the indicators analysed (for instance: number and proportion of NR actors in the networks) confirm that the Swedish openness was much greater than the Spanish. Moreover, NR innovators in Sweden were not only more abundant than in Spain but also better connected to the rest of the network nodes, as the greater average degree and betweenness centrality of such NR nodes reveals. In other words, NR actors occupied a more central position in the Swedish network than in the Spanish one, where they were located in more peripheral and less influential positions. Consequently, the potential influence of external innovators over local resident actors was significantly higher in Sweden, where NR actors could reach a considerably greater number and percentage of local innovators. This fact may influence the process of introduction, diffusion, and further modification of new ideas into the respective national systems of innovation.

Thus, besides the long-term institutional divergence concerning patent institutions in Spain and Sweden stated in section 2, it seems that there were distinct structural dynamics related to the way innovators collaborated in both countries. With similar patent statistics (see Figure 1 and Table 2) the SNA carried out in this section reveals different biases among patentees –inventors and entrepreneurs– that lead to a more connected innovation network in Sweden with respect to Spain. Although we just examine collaboration in patenting, the results affect the whole system of innovation, as knowledge, scientific practices, education, entrepreneurial links, social values scale, and even political attitudes towards innovation and institutional change flow throughout this kind of networks and connected agents. With similar initial backgrounds, the SNA demonstrates that during the nineteenth century collaboration to innovate increased in Sweden while it did not so in Spain.

5. Concluding remarks and further research agenda

During the first half of the nineteenth century, Sweden and Spain were both two relative latecomers to the industrial revolution in the European periphery with similar patent institutions. However, in the years leading up to WW I the countries would embark on two radically different development paths with Sweden emerging as a highly industrialized and innovative country and Spain remaining in a lagging position with a weak system of innovation. Although distinct socio-economic, institutional, and cultural factors may influence on these diverging paths, our focus have been on the study of collaboration patterns among innovators. Thus, the purpose of this work has been to analyse the emerging innovation networks of Sweden and Spain from 1878 to 1914, by applying SNA methods to historical patent data. Considering the differences in the innovation system results over the long term, and according to previous literature that highlights the importance of cooperative attitudes in innovation, we hypothesized that there had to be distinct collaboration patterns among innovators in Sweden and Spain from the beginning.

Indeed, the empirical analysis carried out shows that certain characteristics in the patent networks associated with increased collaboration in innovation started to emerge in both countries during the Second Industrial Revolution. However, in almost all measurements such characteristics appeared more clearly in Sweden than in Spain. The results demonstrate a better collaboration pattern among inventors and entrepreneurs in the former country that is not evident from the analysis of basic patent statistics. This was accompanied by a progressive institutional change towards a stronger patent system in line with that of the most advance economies at the time.

The patent network analysis shows that Sweden and Spain differed in several structural and topological properties that are evident the most in two aspects: network connectivity and openness. All connectivity measures reveal that the network in Sweden was better connected. The proportion of connected innovators was larger in Sweden than in Spain and in the end of our time-period also in absolute numbers. Moreover, the density of the Swedish network doubled that of the Spanish one. This in turn meant that actors in Sweden became more connected as they had up to 25% more links than their Spanish counterparts. Furthermore, if openness to new influences and ideas can contribute to more innovative activity, then the network analysis shows an additional way in which Sweden may have reached an advantage, as non-resident actors in the Swedish network were much more connected and occupied a more central and influential position than in Spain. This could possibly facilitate the incorporation of foreign ideas into the innovation process and the resulting patents. Although we have captured the national networks at their formative stages these properties give us preliminary insights into factors that may represent key differences in the future evolution of national innovation systems in both countries.

Therefore, this work opens new and exciting directions for future research on the history of innovation and technological progress with the application of SNA to historical patent series and similar data. However, this paper has only scratched the surface of the networks analysed. Establishing causal links between SNA results and economic and technological development could help to shed further light on why some countries diverged at the end of the nineteenth century. In other words; are the network structures a result of institutional changes or, more likely, are they part of the cause of such kind of shifts? From a different viewpoint, to which extent can institutional disasters affect collaboration patterns and network evolution? Another natural extension of this work is to extend the period of study into the twentieth century to analyse how wartime affected network structures and the possibilities for collaboration across national borders.

Another direction for future research is the composition of the networks themselves. For example, did firms occupy a more central and relevant position in the Swedish innovation network than in the Spanish? Were better-connected Swedish actors more active in more key technologies than in Spain, thus facilitating collaboration and preventing lock-in effects? Furthermore, in this study we have used the country as the level of analysis, which leaves us with the question of how much heterogeneity exists regionally within countries or to what extent local clusters are responsible for the overall connectivity. Finally, to the extent that historical patent data lack citations to previous art, networks of different technological fields could help us gain further knowledge about the development and hybridization of new technologies.

In *The Evolution of Cooperation* Robert Axelrod (2006, p. 173) demonstrated how collaboration can get started by even a small cluster of individuals "who are prepared to reciprocate cooperation, even in a world where no one else will cooperate". If the "shadow of the future" is strong enough, as usually occurs with innovation activity, collaboration could become stable and thrive in a successful long-term strategy. Through SNA methods applied to historical patent data, our findings demonstrate that there were distinct cooperation patterns in emerging innovation networks that can help further our understanding of how countries can diverge over the long term. We are well aware of the complexity of such evolution and that we have just isolated and examined a tiny piece of an innovation system. Notwithstanding, one possible answer to Garicano's dilemma about when Sweden decided to become Sweden, with respect to the long-term problems of Spain, is straightforward: when Swedish people were more willing to collaborate among themselves, and with foreigners; something that took place already in the late-nineteenth century.

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