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The Uneven Regional Geography of Telecommunication Standard Essential Patents

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Abstract

This paper explores the role of Standard Essential Patents (SEPs) in shaping technological development and regional innovation in Europe's telecommunications sector. Results reveal strong geographic concentration, particularly in Helsinki and Stockholm, which account for one-third of multi-generation cellular network technology SEPs. Unlike other technologies, SEP distribution does not scale with population or prior technological expertise. Findings further suggest a winner-takes-all dynamic, where early SEP leadership reinforces future dominance, yet this advantage weakens across generations. The study offers new insights into standardization's spatial dynamics and underscores the need for long-term perspectives when modeling technological competition and diffusion.

Keywords

Standard Essential Patents (SEPs), Technological Standardization, Cellular Network & Telecommunication Technology, Geography of Innovation, Evolutionary Economic Geography, Regional Knowledge Spaces

JEL: L15, O34, R12

1. Introduction

The primary goal of patenting is to generate market power, the returns of which act as an incentive for innovators to undertake the risky research and development process. Among the many issues that surround patenting and its impacts is the fact that, once an innovation has been patented, the patent holder is able to decide who can use that innovation and for what purpose – along with how much the user has to pay for that privilege. This then creates an incentive for others to develop their own parallel technologies to generate rents for themselves. This competitive approach may have benefits in terms of resilience and synergistic insights. Alternatively, its fractured nature can lead to higher costs in terms of redundant R&D, litigation, and lost economies of scale when the industry does not operate from a common foundation.[1] It can therefore be useful to implement a standard, that is, a common platform followed by an industry.[2] Perhaps the most ubiquitous standards in the public's eye are those governing telecommunications; most people would recognize the terms "3G" or "4G" even if they cannot say what precisely those are.[3]

Standards such as these are created by a Standards Setting Organization (SSO) sometimes also referred to as a Standards Development Organization (SDO). By establishing a standard and identifying the patents it is based on, SSOs create the possibility for returns to scale in an industry.[4] They do so, however, by handing the owners of the patents included in the standard significant market power. Normally, this would give owners of these 'Standard Essential Patents' (SEPs) the ability to command high license fees and limit access for their own benefit. Under the auspices of the SSO, however, SEP holders are expected to provide licenses (generally as part of a larger set of essential patents) on a fair, reasonable, and non-discriminatory (FRAND) basis.[5] Thus, by declaring a patent essential to practice a standard, the SSO creates an opportunity for monopolistic activity well beyond a normal patent, something it then seeks to mitigate ex-post.[6]

Just as SEPs (and patents overall) create concentration in the business world, there is the possibility that they can create concentration geographically. In particular, if a region obtains an SEP at one point in time, this may support further innovation which cements its importance in a technological area. In this paper, we analyze the distribution and evolution of SEPs in Europe to look for precisely such possibilities.

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[1] Tassey (2000) provides an early discussion of the costs and benefits of standards; Yang (2024) provides a more recent review.

[2] Although we focus specifically on standards that utilize SEPs, patents are not the only means of implementing a standard. Others with important economic implications include ISO 9000 which, among other things, has a positive impact on trade (Blind, Mangelesdorf, and Pohlisch, 2018). Disdier, Fontagné, and Cadot (2015) find a similar trade promotion effect from standardization via trade agreements. Overall, the benefits of standard harmonization is quite clear, with Schmidt and Steingress (2022) attributing 13% of global trade growth to harmonization. Note that this is not solely due to product standards harmonization. Levinsohn (2016) provides how standardization of shipping containers had a very important impact on easing international trade.

[3] Hess and Coe (2006) provide a case study of the telecommunications industry and the role standards play in promoting an efficient global supply chain. Henkel (2022) discusses issues surrounding the stage of the global supply chain at which SEPs are utilized, finding a tendency for them to be licensed towards the end of the production line.

[4] This does not, however, always mean that all such identified patents are actually "essential". See Bekkers, et al. (2022) and Lemley and Simcoe (2019) for more discussion.

[5] See Nikolic and Galli (2023) for insights into such "pooling" of SEP patents for 5G.

[6] Lerner and Tirole (2015) discuss the problems of ex-post licensing and, in particular, lament the lack of firm pricing guidelines in most standards agreements. As a result, it should perhaps be no surprise that Love, Lefouili, and Helmers (2023) find that court cases involving SEPs are 12% more likely to involve a claim of opportunistic behavior. Lemley and Shapiro (2013) offer potential solutions involving binding arbitration.

Combining data from the European Telecommunications Standards Institute (ETSI) and European Patent Office (EPO) filings obtained from the PATSTAT patents database, we uncover several stylized facts regarding SEPs in Europe for the telecommunications industry. First, although the number of SEPs has risen over time, this rise is dominated by those patents without *any* European inventors. Overall, only one-third of EPO SEPs include an inventor with an European address. In contrast, nearly half of all non-SEP patents at the EPO include an European inventor. Second, SEPs are extremely geographically concentrated, with two locations (Helsinki and Stockholm) particularly important.

This concentration is not, however, a function of "upscaling" wherein more populous regions produce more patents. In fact, the reverse is true in the H04 technology classification that covers telecommunications patents. Essentially, less populous regions seem to produce more SEPs, and it appears that the lack of relationship between SEPs and population is not a technology-specific phenomenon but is particular to SEPs. Finally, we find very strong indications of hysteresis in SEPs. This indicates that, for example, Helsinki's success in obtaining SEPs early on in their implementation is in large part the reason for its continued success in defining the evolving technological standard. As an extension of this idea, Schott and Schaefer (2023) find that standards proposed by China rarely gain traction. The authors interpret this fact as indicating that those regions which were involved in global standardization from the beginning continue to set the agenda, something lamented by Deng, Li, and Mateut (2022). This interpretation is also supported by our findings in this paper.

Although there is no public information on how much is earned from SEPs, indirect indicators of value can be found. Bekkers, et al (2023) find that SEPs attract far more forward citations than other disclosed patents.[7] Likewise, they find that SEP holders are more likely to assert the rights therein via litigation (although as Love, Lefouili, and Helmers (2023) point out, this may be due to failure to live up to the FRAND commitments). And while there does seem to be a significant first mover advantage in SEPs, this is not to say that standards only benefit the holder of the SEP.[8] Ernst, et al. (2014) argue that by providing a specific target, newly emerging industrial economies can benefit substantially by building to the standard rather than attempting to patent themselves. This idea was further codified in the "signal theory" models of, e.g., Hudson and Jones (2003). In addition, based on data from the UK, Foucart and Li (2021) find that by providing a "target", standards promote innovation. These factors might help explain the evidence provided by Blind, Ramel, and Rochell (2022), which finds that formal European-level standards increase income in EU-15 countries, while patents (total, not only SEPs) and national standards do not. If standards and SEPs create economies of scale and technological certainty, this can foster overall growth.[9]

The rest of the paper proceeds as follows. The subsequent two sections provide an overview of the relevant literature concerning the geography of innovation in an evolutionary context, along further research insights on SEPs, in particular in the telecommunication sector. This is followed by a section that highlights the utilized data sources in the present investigation and an overview concerning overall observed trends in SEPs production. The next section then delves into the geographic

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[7] Bekkers et al. (2024) make the important point that SEPs arise not only from privately funded activities but that government funding is a key part of the process. They find that disclosed SEPs are 14% more likely to cite government-funded research than similar patents.

[8] In an interesting twist to the concurrent R&D problems standards are intended to help mitigate, Herzberg, Denter, and Moehrle (2024) discuss a "watch and wait" strategy in which patent filers do not declare their innovations as essential despite their similarity to SEPs in order to fly under the radar of competitors.

[9] The belief that standards promote efficiency is not universal. Valero-Gil, et al. (2023) find that standards tend to introduce organizational rigidities which, at least for green patenting, tends to inhibit innovation. This may help to explain Clougherty and Grajeck (2023) who find that cutting-edge firms are more apt to abandon existing standards because they are perceived as stumbling blocks more than a common foundation.

distribution of SEPs using both descriptive and econometric techniques, while the concluding section offers a detailed discussion along with concluding remarks.

2. Knowledge Production and Innovation – Evolutionary Considerations

The 'Geography of Innovation' literature (Feldman, 1994) provides much evidence, and even a number of stylized facts (see Feldman and Kogler, 2010 for a detailed overview), as to why knowledge production and spillovers are localized, and why innovation processes and outcomes are concentrated in space. In general, the agglomeration of individuals and firms operating in a particular sector on the one hand generates significant benefits due to localization economies (Marshall, 1890), while the agglomeration of a variety of sectors in a single location, such as dense urban areas, on the other hand offers ample opportunities for inducing technological change and innovation due to the cross-fertilization of ideas (Jacobs, 1961). Following these notions, empirical evidence shows that inventions, i.e., novel products and processes that hold economic value, are particularly concentrated in space, frequently clustering in agglomerations where dense networks of knowledge production processes, institutions, firms and skilled labor promote innovation (Carlino et al., 2007; Chattergoon and Kerr, 2022). In addition, studies have shown that invention exhibits super-linear scaling with respect to population size (Bettencourt et al., 2007). Essentially, as city populations double, invention (e.g., patent output) more than doubles. This pattern indicates increasing returns to scale in urban innovation systems, driven by intensified social interactions, agglomeration economies, and cumulative knowledge dynamics.

However, the sheer spatial concentration of actors and entities that engage in activities that aim to produce economically valuable knowledge is not a guarantee for generating technological advancements and capacities that eventually result in increased productivity, but rather it requires certain mechanisms, processes, organizational configurations and institutional settings that facilitate and enable knowledge flows and spillovers. Historical accounts, anecdotal evidence, and meta-narrative reviews emanating from various scientific fields certainly provide valuable insights about the why, when, and how innovation is produced in particular context and spaces, but also about the ways it accumulates and diffuses over time (Greenhalgh et al., 2005; Rosenberg and Birdzell, 2008; Mokyr, 2010; Feldman et al., 2017; Vermeulen and Guffarth, 2017). In the context of the latter it is especially the Evolutionary Economic Geography (EEG) literature that offers some relevant systematic empirical evidence, embedded in versatile theoretical grounds that pair traditional thinking along the lines of Marshall and Jacobs with ideas of generalized Darwinism, complexity and network theory, and system properties more generally (Grabher, 1993; Martin and Sunley, 2007; Essletzbichler and Rigby, 2007, 2010; Kogler, 2015). As such EEG inquiry has produced a significant body of research over the past couple of decades that highlights ideas and concepts for explaining change in economic landscapes, and in particular in the context of technological change and innovation, while also providing advanced empirical findings based on systems and network perspectives (Uyarra, 2010; Crespo et al., 2013; Kogler et al., 2023a).

The probably most profound of these findings, and centered around the notions of path-dependency (Martin and Sunley, 2006), demonstrates that relatedness plays a crucial role in explaining place-based trajectories of technological development and diversification (Boschma, 2017, Whittle and Kogler, 2020). Building on the notion that knowledge is largely localized, the underlying rationale is that new knowledge will build on existing foundations, i.e., path-dependency, and further that such new knowledge will generate competitive advantages if it is especially embedded in the local knowledge space (Kogler et al., 2013; 2017). Specifically, by assessing how frequently technologies appear together, e.g., by measuring the co-occurrence of patent classes listed across single patented inventions, one can then estimate how closely related different fields are. In a further step it is then also possible to estimate a region's likelihood to diversify into certain new specializations based on the assumption that technologies closely aligned with existing capabilities are more likely to enter and stimulate further innovation than those that are further removed from the core competencies present at a particular place. At the regional level, technological relatedness is widely recognized as a key driver of technological change, shaping the direction and pace of innovation (Boschma et al., 2015). Technological relatedness scores among knowledge domains, frequently visualized in a network representation and labelled the 'knowledge space' (Kogler et al., 2013), vary from place to place and, albeit slowly, change over time. This dynamic can lead to periods of stability, during which a region benefits from its established specializations over extended periods. At the same time, it can also open windows of opportunity, allowing regional economies to branch into new, high-growth specializations driven by shifts in the technological landscape (Kogler et al., 2023b). In both cases, it becomes crucial for regions and their firms to maintain a stake in widely adopted technical standards, either through established invention portfolios or by shaping emerging standards through novel local innovations. This is especially important given the growing significance and market value of standard-essential patents.[10]

3. Standard Essential Patents – Meaning, Process, Relevance

Standard Essential Patents are a relatively new development, emerging from Standards Setting Organizations' intellectual property rights policies over the last thirty years. ETSI itself evolved from a loose coalition of European telecom providers working together to implement GSM or 2G cell protocols. This informal arrangement became ETSI in 1988 at the behest of the European Commission, with the stated goal of accelerating European telecommunications development. ETSI itself did not recognize an 'essential' patenting until 1994, where it defined SEPs as patents that are "technically but not commercially" impossible to use the standard without. (Contreras, 2018). ETSI's definition of essentiality is one of the earliest and predates similar definitions by other influential SSOs like ANSI and IEEE by over a decade. Contreras, 2018 provides a detailed survey of the history of SEP development in ETSI and other popular SSOs (Contreras, 2018).

According to ETSI (and most other SSOs), SEPs are patents that are 'technically impossible' to use the standard without. Implicit in this definition is the core issue with SEPs – by practicing the standard, an organization admits to using a company's patented technology. In other words, any company that makes a device that communicates using 3G/4G or WiFi, or streams videos using MPEG, or compresses them with HEVC, must purchase a license to these SEPs or risk suit for patent infringement. These technologies, especially in the telecommunications space, are so pervasive that it is practically impossible to avoid them. This gives holders of SEPs incredible power over would-be users of the standard. FRAND policies have arisen to attempt to combat the potential abuses of this power.

FRAND stands for "fair, reasonable, and non-discriminatory" and is intended to prevent SEP-holders from exerting monopolistic and anti-competitive control over their portfolios. Under the auspices of "fairness", licensors are not meant to discriminate against licensees, regardless of their position in the supply chain or if their status as a competitor. In reality, licensors discriminate for exactly those reasons. As Sung, 2023 notes, SEP holders often choose to grant licenses only to

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[10] Factsheet on standard essential patents: https://single-market-economy.ec.europa.eu/publications/factsheet-standard-essential-patents_en

manufacturers of final goods (where revenues and thus royalties are higher) as opposed to manufacturers of components and other intermediate goods (Sung, 2023). Likewise, SEP holders also deliberately delay or exclude competitors, so called ‘hold up’ and ‘hold out’ on license agreements. Indeed, Love et al. 2023 find that 73% of all SEP litigation in US District Courts is from this type of opportunistic behavior, with ‘hold up’ being the most common form (Love et al., 2023). Because SEP holders and would-be licensees can rarely come to agreement, courts are often left to determine how much a FRAND license is worth. This is a huge inefficiency in the SEP system, and has faced considerable criticism and clamor for reform. Lemley & Shapiro, 2013 propose a final offer, binding-arbitration style solution to prevent clogging the courts and otherwise holding up the licensing process (Lemley & Shapiro, 2013).

An infamous recent example of this opportunistic behavior was the ‘Smartphone Wars”. The Smartphone Wars started approximately fifteen years ago when Apple, Google, and Microsoft first entered the mobile phone market with their own devices and operating systems. As documented in detail by Jones, 2014 and Cotter 2014, the incumbents, Ericsson, Motorola, Nokia, and others, were loath to grant licenses to these tech giants, and did so only at extortionate prices[11](Jones, 2014; Cotter, 2014). Perhaps the most famous case to come out of the Smartphone Wars was Huawei v. ZTE in 2015.

Huawei sued ZTE in Dusseldorf, alleging that ZTE was not negotiating in good faith and merely going through the motions of FRAND. The case was referred to the Court of Justice of the European Union (CJEU) to clarify what exactly a FRAND licensing discussion looks like, and when SEP holders should be considered uncooperative. The CJEU’s decision sought to prevent abusive conduct of SEP holders, protect the much weaker licensees from competition-stifling injunctions, and formalize the often contentious FRAND process (Pentheroudakis & Baron, 2017). The outcome of Huawei v. ZTE and the Smartphone Wars led to anti-trust investigations by the European Commission into Motorola and Samsung and was likely the starting point for the Commission’s sweeping 2023 proposal to reform SEPs in Europe[12] (Jones, 2014).

As with FRAND, the definition of what is truly ‘essential’ has also been stretched. Standards such as 3G/4G contain thousands of SEPs, making it virtually impossible to determine an individual patent’s contribution to the standard. Instead, would-be standard users must license bundles of patents (often derisively referred to as ‘thickets’ due to their dense, entangled nature). As discussed by Contreras, 2018, there is an epidemic of 'over-declaration’ of SEPs, and very little recourse to challenge such declarations within an SSO (Contreras, 2018).

Instead, aggrieved parties must file complaints with competition authorities, or otherwise try their luck with the courts. In the case of ETSI specifically, studies conducted by Fairfield Research have found that only 28 percent of 2G SEPs, 29 percent of 3G SEPs, and 50 percent of 4G SEPs were actually ‘essential’ (Fairfield, 2008, 2009, 2010; Contreras, 2016). Gaessler et al., 2020 also use ETSI data, but create their own measure of essentiality by measuring the semantic overlap between declared SEPs and the text of the standard itself. They similarly find essentiality rates of 31 percent, 34 percent, and 36 percent for LTE, UMTS, and GSM standards respectively (Gaessler et al., 2020).

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[11] In 2012, Samsung sued Apple in The Hague to enjoin Apple from selling phones and tablets that used its UMTS technology, after Apple declined a royalty of 2.4% of all revenue from sales of the devices. Samsung contended that such a royalty was in keeping with FRAND. The court thought otherwise. Jones 2014.
Similarly, Microsoft sued Motorola in 2010, arguing that a 2.25% royalty was not in keeping with FRAND principles. For a detailed discussion, see Cotter 2014.

[12] See Leanza, 2024 for a detailed discussion.

Related to the issue of essentiality is membership in the SSO itself. Individuals must typically be nominated and accepted to join standards setting committees. These committees are run by prominent figures in their given field, who oftentimes are employees of large technology companies with vested interests in the standard. To make changes to the standard, individual members must make proposals within a working group, which then brings those proposals to a technical specification group. However, as Schott & Shaefer, 2022 note, individual proposals must be supported by at least four other member organizations to be considered. This often leads to a very small minority of standards members making most of the changes (Schott & Shaefer, 2022).

This is a natural conflict of interest. Large incumbents decide not only what patents are essential to a standard, but who gets to participate in making that determination. Contrerras, 2016 finds that for telecommunications especially, this process leads a stark division of 'haves' and 'have-nots', where the 'haves' are large, established, western firms such as Motorola, Qualcomm, Ericsson, and Nokia (Contreras, 2016). Similarly, Jones, 2014 discusses the anti-trust issues raised by this process in detail and highlights some of the preliminary investigations the European Commission has launched into SEPs (Jones, 2014). While SSOs are private enterprises and technically not regulators, the SEP inclusion process is still a classic case of regulatory capture by industry.

This large incumbency bias also leads to stagnation in standards and reluctance to release new standards. Baron et al., 2011 find that the addition of SEPs to a standard delays the release of new standards, and instead promotes smaller 'updates' to the standard (Baron et al., 2011). In the case of 3G, that means that SEPs are constantly being added to the standard, even as newer standards such as 4G, 5G, and now 6G are being developed. This leads to a considerable bloat of SEPs in the standard, which further exacerbates the essentiality issues discussed above.

The patent bargain offers a twenty-year legal monopoly in exchange for disclosing technical know-how. SEPs amplify this monopoly position by forcing consumers of the standard to license their technology. There are tremendous inefficiencies and abuses in the current system. It is largely self-policed. Members of incumbent multi-nationals make up the SEP committees of the SSOs and declare their patents as 'essential'. The definition of essential is also murky, leading to huge pools of patents being continuously added to the standard and slowing down the standard renewal process. FRAND is an open question and must be frequently litigated in court, which is costly and time consuming. All these factors give tremendous power to incumbents, and has been discussed thoroughly in the literature above. What is still lacking in the literature, however, is an analysis of how this imbalance of power shapes the geography of innovation in patent-intensive, standardized technologies. We turn to evidence from telecommunications sector in Europe to answer this question.

4. Data Sources and Initial Analysis

The 3rd Generation Partnership Project (3GPP) was established in 1998 to unite Standards Development Organizations (SDOs) worldwide, aiming to create a platform for managing the technical specifications for the third generation of mobile telecommunications[13]. As one of its members, the European Telecommunications Standards Institute (ETSI) requests interested parties to declare any patent or patent application deemed essential or potentially essential to its Standards

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[13] https://www.3gpp.org/about-us/introducing-3gpp

and Technical Specifications.[14] Therefore, the ETSI keeps a list of all Standard Essential Patents (SEPs) filed within its jurisdiction. It provides a list of all patents related to 2G, 3G, 4G, and 5G standards in Europe.

We use the ETSI IPR Online Database[15] to retrieve the application number of all SEPs covered by the institute, and we use this information to identify the SEPs in a comprehensive sample consisting of every patent filed with the European Patent Office (EPO) collected from PATSTAT. According to the European Commission, the ETSI database represents over 70% of worldwide SEPs.[16] We find 4,029 SEPs in PATSTAT and retrieve metadata on each one, including its priority year, addresses, and Cooperative Patent Classification (CPC) codes. This database serves as our primary source for studying the geography of standards in Europe.

Figure 1 displays the total number of SEPs from 1997 to 2016 according to the patents' priority year.[17] In dark gray, we highlight those SEPs that list at least one inventor based in Europe. Although our database covers only patents filed with the EPO, only 34% of the patents mention a European inventor.[18] For reference, studying every patent published during the same period, we find that 47% of those include at least one EU-based inventor. This result suggests that Europe is perhaps not a significant player in the global telecommunication standards. Instead, the continent adopts or follows the standards set elsewhere, with East Asian countries and the United States serving as the primary SEP developers. This is also highlighted in histograms provided in Appendix I that illustrate the number of SEP applications across major contributing countries, i.e., based on inventor address information, during the 3G and 4G periods.

Figure 1 also reveals two growth regimes regarding the annual production of SEPs. These correspond to and match the two generations of mobile telecommunications standards covered in our sample - 3G (2001-2009) and 4G (2009-2020).[19] Along these lines, we divide the sample into these two periods to examine the dynamics of 3G and 4G SEPs in Europe.

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[14] https://www.etsi.org/standards/types-of-standards

[15] https://ipr.etsi.org

[16] https://www.eesc.europa.eu/sites/default/files/files/factsheet_-_standard_essential_patents_1.pdf

[17] Our PATSTAT version includes patents up to 2019. However, it takes time for authors to declare their patents to the ETSI, which delays their addition to the database. So, due to truncation, we can only identify the SEPs up to 2016.

[18] Essentially, based on the ETSI data that was provided we subsequently matched all but a 6.9% with PATSTAT (appln_id) and then it was possible to retrieve the "family id" to ensure only single records per patent enter the analysis; the advantage of using EPO data is that it has a high coverage of inventors' addresses which in turn allows for the regional allocation of inventions.

[19] Given the time lags with patent disclosure, we focus on the 3G and 4G innovation waves. This both overcomes end of sample truncation and provides a longer time horizon for our analysis. Buggenhagen and Blind (2022) provide a overview of leaders in 5G. Perhaps unsurprisingly given our results on persistence, they identify the same major players that we do.

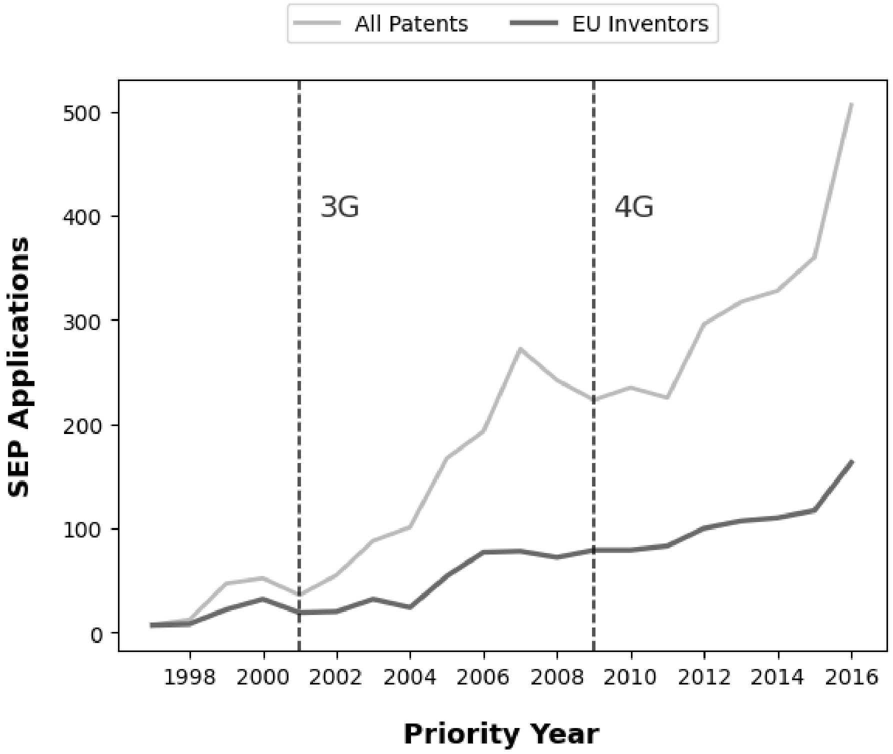

Figure 1: The y-axis represents the number of SEP applications, and the x-axis indicates the priority year of the patents. The light grey bars display the total count of patents in our sample, while the dark grey one shows the number of applications that include at least one inventor residing in the EU.

Regarding the SEPs classification codes, 99% of all the patents belong to the same 3-digit CPC - H04, Electric Communication Technique. The second most common CPC code, Y02, is a general tag used for identifying patents related to adaptations against climate change and is found in only 7% of all SEPs. This distribution remains similarly skewed when we examine the 4-digit CPC codes. Wireless Communication Networks (H04W) account for 88%, while Transmission of Digital Information (H04L) makes up 60% of all SEPs (Appendix II). These findings are not surprising, considering we are examining telecommunications standards, but they reinforce our identification of the SEPs. More importantly, this data will help us to explore the relationship between regional specialization and the production of SEPs. Specifically, we can use these results to analyze how the production of H04 code relates to and potentially predicts the geographical distribution of SEPs.

5. Geography of Standards

Using the ETSI report, we identified 1,397 SEPs with at least one inventor residing in Europe. We geocoded their addresses and assigned each inventor to one metropolitan area. We then counted all patents listing an inventor living in the area to measure its total SEP production and used this information to plot the spatial distribution of standard patents.

Figure 2 shows two histograms representing the top ten regions in Europe with the most SEPs during the 3G and 4G periods. Most of these patents are concentrated around Helsinki, while Stockholm played a significant role during the 4G period. These two cities account for 33% of all standard patents produced on the continent.

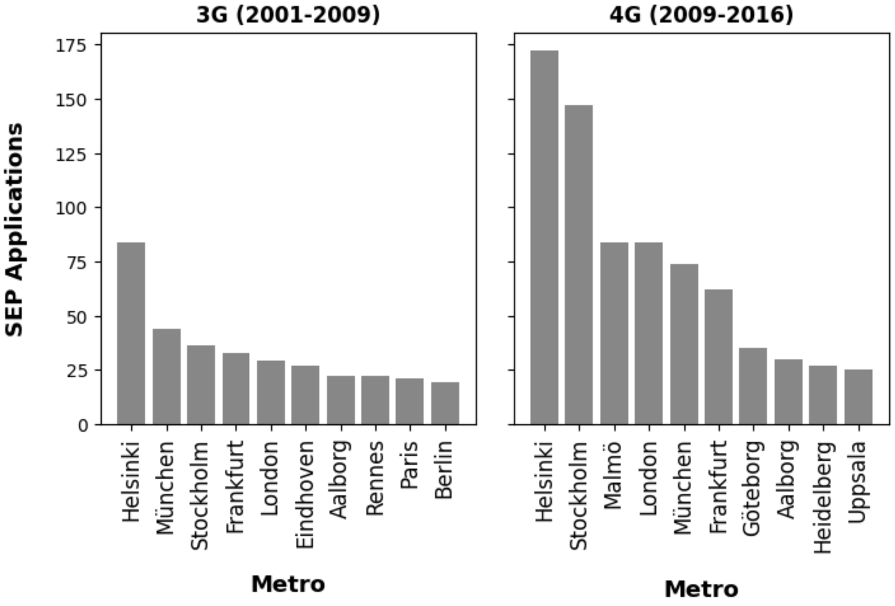

Figure 2: The histograms illustrate the total number of SEP applications by metropolitan area during the 3G and 4G periods. The y-axis represents the count of all patents that include at least one inventor residing in the area during the specified period. The x-axis displays the top ten EU metropolitan areas ranked by their SEP production for that time frame.

Since patents can list inventors from multiple metropolitan areas, there is a risk of double counting when we sum all SEPs with at least one local inventor. One alternative approach is to assign shares to each metropolitan area. For instance, if a patent lists one inventor in Stockholm and another in Malmö, we could allocate a 0.5 share to each region, allowing us to combine these shares to measure relative production. We reproduce the results from the histogram using relative shares in Appendix III. We observed no significant differences in the core results, aside from changes in the ranking of some Swedish metropolitan areas due to inventors working for Ericsson and collaborating on patents with the Stockholm office.[20]

The standard essential patents covered by the ETSI reports are highly concentrated in space. But how does it compare to other technologies? Are the standard patents more clustered in space than other wireless communication technologies? To answer this question, we measure the dispersion across metropolitan areas using the entropy formula (Shannon, 1949):

$$\mathrm{H} = -\sum_{\mathrm{i}}^{\mathrm{N}} \mathrm{p_i} \log(\mathrm{p_i})$$

where p_i is the share of patents produced in each metropolitan area *i* during the period. We use the entropy formula to measure the average level of uncertainty associated with the spatial distribution of patents. If all standard essential patents come from the same region, we always know with certainty which region produced the patent. We always know the location of the patent holder, and entropy equals zero. Conversely, if patents are equally likely to come from any metropolitan area,

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[20] For the remainder of the paper, we will use the count of patents that list at least one inventor residing in the metropolitan area as our primary metric for the number of SEPs. Although we do not present the results here, we performed additional analyses using shares to confirm the robustness of our findings.

we reach a state of maximum entropy. Most distributions typically fall somewhere between these two extremes, and we use entropy to measure the balance of the spatial distribution of patents, helping us understand how evenly patents are distributed across different regions.

We calculate the entropy of the spatial distribution for all 3-digit and 4-digit CPCs. Figure 3 shows the density plot of these estimates. We include a dark red line highlighting the values we get when using the sample of the standard essential patents collected from the ETSI report. We also include a light red line representing the estimates using only the H04 patents.

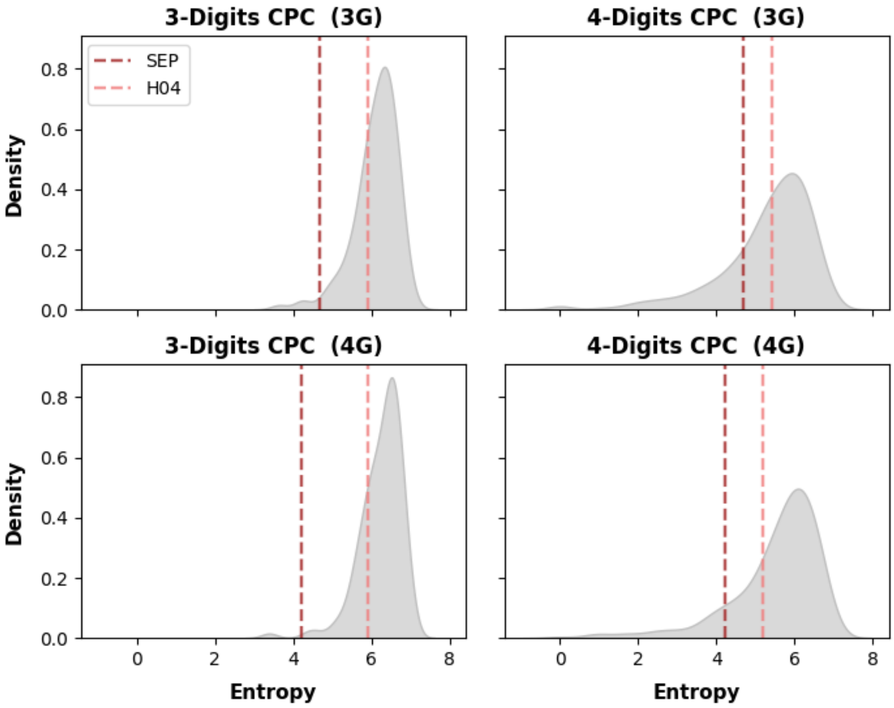

Figure 3: The figure shows four density plots illustrating the distribution of entropy, our measure of the spatial concentration of patents. We estimate entropy using Shannon's (1949) formula to evaluate how evenly patents are distributed across all metropolitan areas. The lower the entropy, the more concentrated the patents are in a few specific locations. The plot shows the density function of these estimates when we apply the formula to all patents containing a 4-digit or 3-digit CPC during the 3G and 4G periods. We include dashed vertical lines representing the estimates using the SEPs (dark red) and the H04 patents (light red).

The standard patents are in the bottom percentile during the 3G period - 20th for the 4-digit and 2nd for the 3-digit. The entropy for the standard patents dropped during the 4G period and so did its ranking - 10th percentile for the 4-digits and 1st for the 3-digit. The same results also hold if we use other estimates to measure the distribution of patents across metropolitan areas - e.g., the Gini coefficient (Appendix IV).

More importantly, we are only comparing the distribution of patents across the metropolitan areas. We do not account for the geographical proximity between those areas. So, we are likely underestimating the geographical concentration - as many other Swedish and Finish regions are also among the top SEP producers.

5.1 Urban Scaling

Previous research highlights the relationship between the distribution of technologies and innovation in urban areas, particularly emphasizing the increasing returns to patenting as a scaling function of metropolitan size, that is, population (Bettencourt et al., 2007). In other words, when we examine the concentration of human activity in space, we find that “the top ten most innovative cities in the United States account for 23% of the national population but generate 48% of its patents” and that this “spatial concentration of productive activities increases with their complexity” (Balland et al., 2020). Indeed, comparing the scaling factors obtained for the different patent classes, the authors find that complex activities, like semiconductors or nanotechnologies, tend to cluster disproportionately in a few large cities. In contrast, less complex ones are more evenly distributed.

Along these lines, given the results shown in Figure 3, we are inclined to ask whether the same pattern holds for the standard essential patents. We want to measure how the production of standard patents scales with the metropolitan population and how it compares with other communication technologies. To explore this question, we draw on previous research and perform a linear regression comparing the patent production against population, using a logarithmic scale for both variables. We then check if the estimated parameter beta is greater than one. If it is, we can infer that patenting volume does not increase proportionally with population in a linear manner (one-for-one), but rather increases superlinearly, i.e., we find increasing returns as a scaling function of population.

Figure 4 shows scatter plots between the natural logarithm of the total count of patents produced in a metropolitan area between 2001 and 2016 and the logarithm of its average population size in 2016. We collect information about the population size of each NUTS3 region in Europe from Eurostat and use a concordance table to aggregate this population into the different metropolitan areas. For this analysis, we are ignoring all regions with no patent applications during the period, as we cannot find the logarithm of zero. Panel A displays the correlation between total SEPs and population. For reference, we also include plots for the total number of H04 patents and the two most frequent four-digit CPCs among the standard essential patents - H04W is in 88% of all SEPs, while H04L is in 60% of them. All figures include the estimators for the trend parameter.

The estimations for the trend parameter beta using the H04, H04W, and H04L patents confirm and fit the many previous reports linking urban population size and patenting volumes. For example, the values we estimate for the H04W and H04L patents closely track those first estimated by Bettencourt et al. (2007) using a sample of all patents per metropolitan area in the US - 1.25. Likewise, these estimates resonate with the findings of Balland et al. (2020), who split their sample according to the NBER technological classes and showed that complex codes like Surgery & Medical Instruments (β=1.61) or Computer Hardware & Software (β=1.57) have a much higher scaling exponent than Earth Working & Wells (β=1.08) or Pipes & Joints (β=1.10).

In contrast, the results in Panel A indicate that the parameter for the SEPs is not only less than one, but its value is also significantly lower than all other estimates found in the existing literature and compared to most other CPCs in our sample. Figure 4 only shows four selected CPCs, but we can plot the probability density distribution of all estimated beta parameters using the 3-digit and 4-

digit CPCs (Appendix V). Along these lines, we find that the estimates for the SEPs are in the bottom 20th percentile among the beta parameters we collected using the other CPCs.[21]

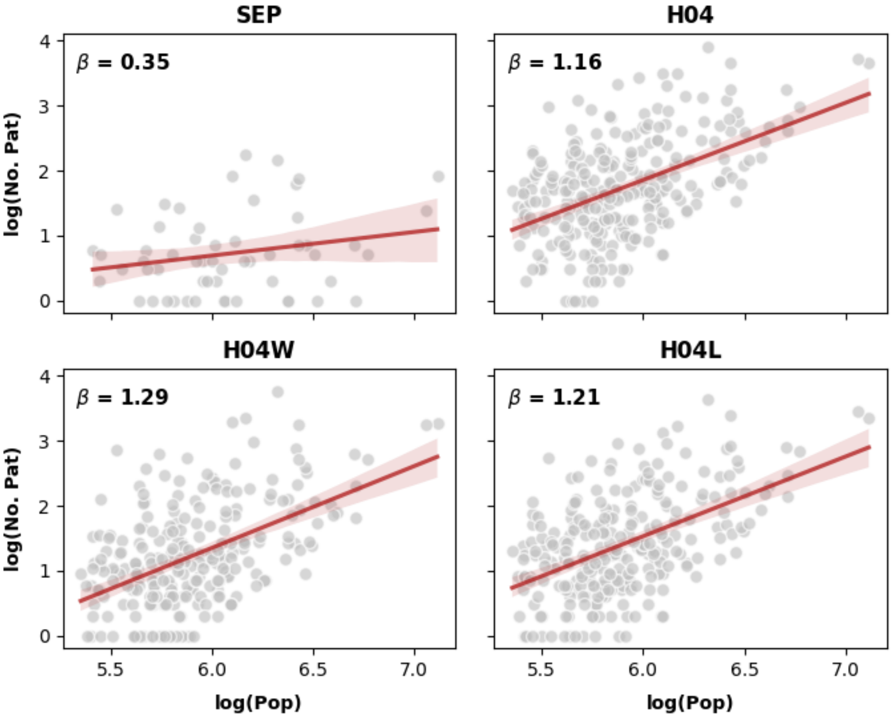

Figure 4: The figure depicts four scatter plots between the number of patents produced in a metropolitan area during the 2001-2016 sample (y-axis) and its population size in 2016 (x-axis). The plots use a log-log scale. We include a linear regression between the two variables in red and we report the estimates for the trend coefficient (β) on the top left corner of each plot.

The results in Figure 4 can be hard to interpret for those unfamiliar with the literature on urban scaling (Bettencourt and West, 2010), so it is worth expanding on them. Compared to most linear regression models used in economics or social sciences seeking to measure a statistically significant impact of one variable over the other, we are not interested in showing that the metropolitan population influences the number of SEPs. We should always expect a positive and significant correlation between population size and patenting activity. It would be unusual for this correlation not to exist. However, what truly matters is the magnitude of this effect.

Because we often expect a positive correlation between population and patenting, a common approach in the literature is to divide the number of patents by the population size to conduct a per capita analysis -- we could use the number of inventors in a region as a more effective control variable. When doing so, we implicitly assume a linear or one-to-one correlation between these two

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[21] Given the significant differences regarding the number of patents per CPC, one could argue the sample size impacts these estimates. These concerns are valid since our estimates are considerably smaller than those found by Balland et al. (2020), who used NBER codes. NBER's classification scheme divides the sample into less hierarchical classes, resulting in more patents per class. Therefore, to ensure our results are robust, we randomly sampled 1,000 patents from each CPC and repeated the analysis 100 times. We plot the resulting distribution in Appendix VI. Although the entire probability density function shifts to the left as all betas decrease, the estimates for the SEPs remain in the bottom 20th percentile.

variables. In other words, as the population grows by a factor of one, we expect that patenting will also increase by a magnitude of one. We represent this relationship as:

$$\mathrm{Y(N)} \propto \mathrm{N}$$

However, the urban scaling literature shows that this assumption often fails. Instead, it's more accurate to describe the relationship between population and any other variable as:

$$\mathrm{Y(N)} \propto \mathrm{N}^{\beta}$$

Therefore, the linear regressions plotted in Figure 4 try to capture the size of this scaling parameter beta for the different patent classes. In doing so, we are trying to build our analysis on the "many empirical studies over the past 40 years" pointing out that "most urban properties, Y, vary continuously with population size and are well represented mathematically on average by power-law scaling relations on the form of $Y = Y_0 N^{\beta}$." More importantly, we are specifically trying to compare the scaling behavior of technological standards compared to the empirical regularity that "one generally observes that rates of social quantities (such as wages or new inventions) increase per capita with city size (superliner scaling, $\beta = 1 + \delta > 1$, with $\delta \cong 0.15$) whereas the volume occupied by urban infrastructure per capita (roads, cables, etc.) decreases (sublinear scaling, $\beta = 1 + \delta < 1$). Thus, these data summarize familiar expectations that larger cities are not only more expensive and congested, but also more exciting and creative when compared to small towns" (Bettencourt, 2013).

This empirical observation forms the basis of our analysis. We do not want to confirm a positive and statistically significant relationship between population size and SEP production. We find this to be evident and trivial. Instead, we seek to estimate the rate at which the expected number of SEPs increases as the population grows and to compare this finding to previous results illustrating the superlinear scaling of innovation in urban centers. Along these lines, we find that the SEPs do not follow the same patterns as those observed by Balland et al. (2020) for other complex technologies, nor the results summarized by Bettencourt (2013). It scales sub-linearly with population, almost like the urban infrastructure, rather than the emergent social phenomena like creativity, novelty, and innovation.

5.2 Knowledge Relatedness

Another stylized fact of economic geography is that knowledge-relatedness drives the specialization and diversification of regions (Boschma 2017; Whittle and Kogler, 2020). Since we are studying the spatial distribution of 3G and 4G technologies, one would expect SEP production to primarily occur in regions skilled in knowledge related to telecommunications or wireless networks.

Nearly all standard patents in the ETSI sample fall under one 3-digit CPC, so we can ask how H04 regional capability affects SEP production. Figure 5 shows a linear correlation between the number of standard essential patents and total H04 production.

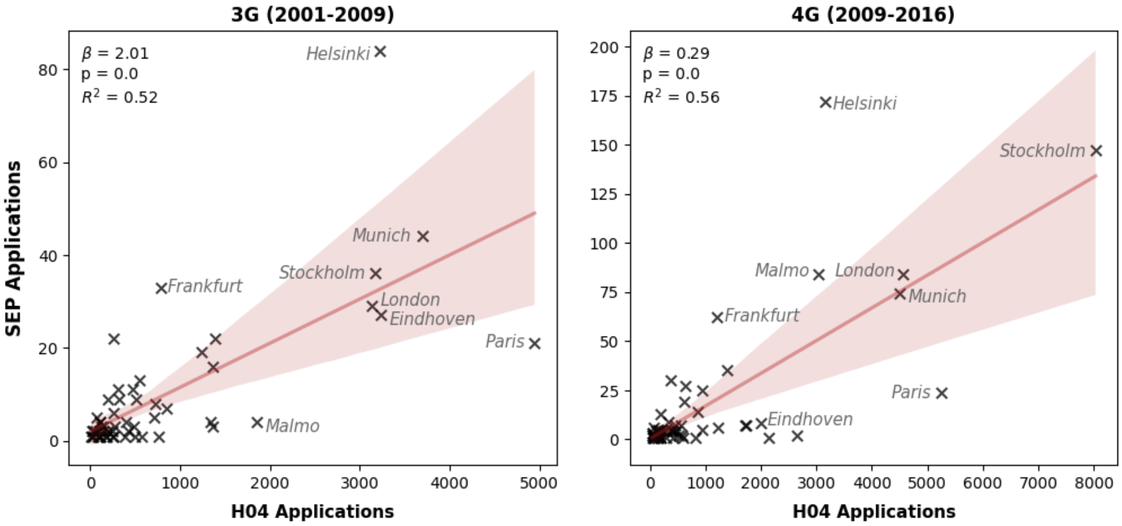

Figure 5: The x-axis shows the count of all H04 patent applications containing at least one inventor residing in the metropolitan area during the 3G and 4G periods. The y-axis represents the number of SEP applications during the same time frame. In red, we present the graphical representation of a linear regression, along with its estimations in the top left corner.

Producing H04 seems like a necessary but not sufficient condition for producing standard essential patents. Stockholm, for example, is a major H04 player and eventually becomes the top SEP producer in Europe. Meanwhile, other large producers like Paris or Eindhoven do not produce many SEP patents – especially during the 4G when Eindhoven only files one SEP patent, despite being the headquarters of Phillips, one of the largest electronics patenting firms in the continent. Other regions, most notably Helsinki, produce a lot more standard essential patents than one would expect given their H04 output.

The total number of H04 patents in a region is perhaps not the best measure of regional specialization. Places like Paris and Munich produce multiple patents across all CPC categories. They might hold numerous patents in electric communications. However, relative to other technologies, those applications are not as abundant. We expect the SEPs to concentrate in regions with a comparative advantage in producing H04 rather than in areas with the highest number of H04 patents. Thus, to measure the link between H04 knowledge production and SEPs, we employ two standard metrics in the economic geography literature. We measure the region's Revealed Comparative Advantage (RCA) and their relatedness density[22] (Boschma et al., 2015). We find similar results using both these variables (Appendix VIII).

5.3 Reinforcement Process

To understand the forces behind the spatial distribution of SEPs, it would help if we could forecast the total number of SEPs in a metropolitan area for a given year based on its knowledge structure and various socio-economic parameters. Thus, we can start by modeling the creation of SEPs as a

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[22] While we do not report the results in this paper, we reproduced the same analysis using the 4-digit CPCs. To measure regional specialization using the 4-digit codes, we first estimate the RCA and relatedness density values for every CPC listed in the SEPs and take a weighted average across these values. We weight each CPC according to the share of SEPs containing it. We find equivalent results using this approach.

stochastic process where the likelihood that a region produces a new standard patent depends on its total H04 output at time *t*. In other words, we assume that the region's H04 production captures all factors that affect its ability to produce telecommunication technologies. The H04 production symbolizes all the capabilities and skills needed to make a new standard patent. Alternatively, we can interpret this basic model as a process where we randomly assign the H04 patents as the standard technology. Following this logic, we can estimate the probability that one region applies for a new SEP at time *t* as:

$$\mathrm{p_{it}} = \frac{\mathrm{H04_{it}}}{\sum_{\mathrm{j}}^{\mathrm{N}} \mathrm{H04_{jt}}}$$

In this stochastic process, the only variable we use to forecast SEP production is the regional specialization in H04 technologies. The only thing that matters is the region's total H04 production. Therefore, this scenario is not different from the correlations depicted in Figure 5 and Appendix VIII, and we can already anticipate how the model will perform. For example, based on the previous session, we ought to expect that if we run such a stochastic model, it will overestimate the number of SEPs produced in Paris or Eindhoven and underestimate Helsinki's production.

We can reframe this model as a reinforcing process that increases the likelihood of applying for a new standard patent over time based on the number of SEPs the region has produced in the past. We can modify the stochastic process to include another component stating that a metropolitan area is more likely to apply for SEP if it has done so in the past. As a result, regions with a history of patenting are more inclined to continue producing patents. This approach allows us to incorporate the concept of increasing returns, the "rich get richer" effect, used to describe the competition among technological standards (Arthur, 1989; Kim et al., 2017; Henrich, 2018). Consequently, we estimate the likelihood of producing an SEP patent at time t as:

$$\mathrm{p_{it}} = \frac{\mathrm{H04_{it}}}{\sum_{\mathrm{j}}^{\mathrm{N}} \mathrm{H04_{jt}}} * \left[\frac{\sum_{\mathrm{t}}^{\mathrm{T}} \mathrm{SEP_{it-1}}}{\sum_{\mathrm{j}}^{\mathrm{N}} \sum_{\mathrm{t}}^{\mathrm{T}} \mathrm{SEP_{jt-1}}} + \frac{1}{N}\right]$$

We can use different methods or strategies to implement the logic outlined by this stochastic process. For instance, if the first process we discussed is equivalent to the linear correlation between the number of SEPs and H04 knowledge production, we can also represent the second model as a linear regression including an auto-regressive component:

$$\mathrm{SEP_{it}} = \beta_0 + \beta_1 \mathrm{H04_{it}} + \beta_2 \mathrm{SEP_{it-1}} + \epsilon_{\mathrm{it}}$$

Given the nature of the dependent variable and the volume of regions without any SEPs during the entire period, we implemented this regression as a zero-inflated negative binomial model. We saved the estimates and used them to predict the share of SEPs produced by each metropolitan area during the 3G and 4G periods. Figure 6 plots these predictions against the actual shares. The plot includes a dotted black line along the 45-degree mark for reference. This exercise shows that when we rely solely on the H04 production to estimate the share of SEPs, we overestimate the size of areas like Stockholm or Paris while underrepresenting Helsinki's shares. However, by incorporating the autoregressive component, we can improve predictions for Stockholm and the others, although we then overestimate the size of Helsinki's dominance.

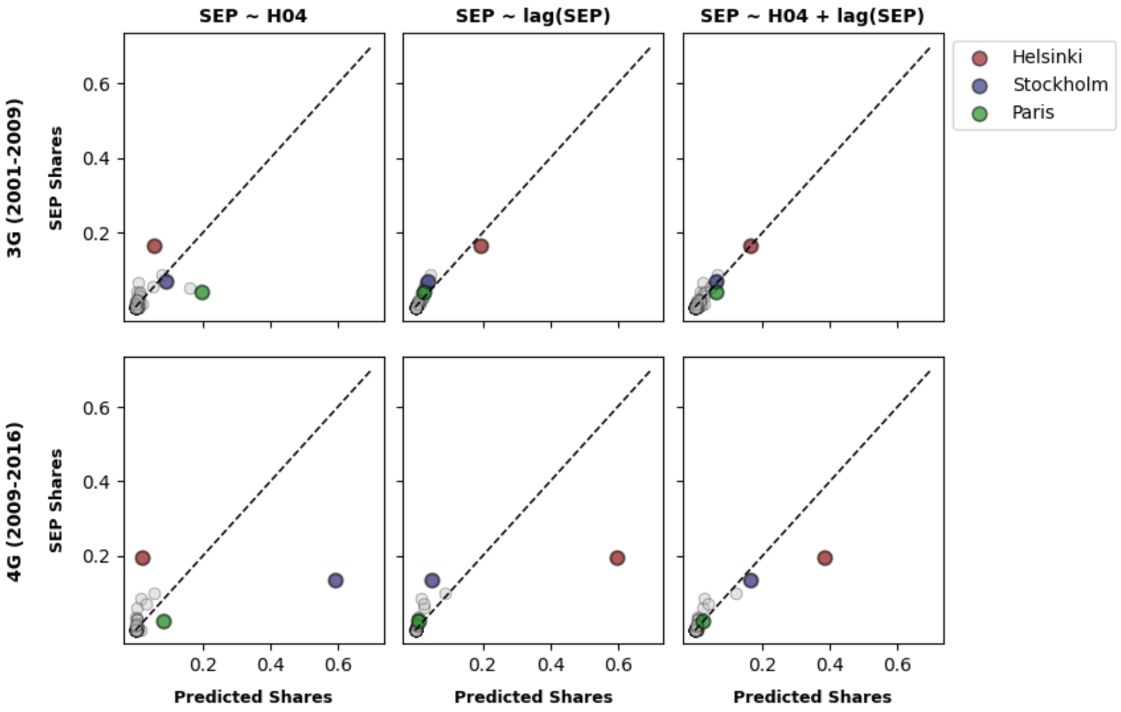

Figure 6: We ran three zero-inflated negative binomial regressions and used their estimates to predict the yearly number of SEPs per metropolitan area. In the x-axis, we show these predictions after adding all predicted applications during the 3G and 4G periods. The y-axis displays the actual values observed during the period. For reference, we include a 45-degree line in black and highlight the outputs of three metropolitan areas - Helsinki, Stockholm, and Paris. The first column shows the output when we regress the number of SEPs against the H04 production. In column two, we regress the number of patents against the values for the previous year, and column three uses both the H04 production and this autoregressive factor.

We validate these results through an additional exercise in which we sample the H04 patents to estimate the SEP production according to the stochastic process described earlier. One advantage of sampling patents instead of relying on the regression analysis is that we can fix the yearly number of SEPs to match their actual size. For example, we ensured we sampled 63 patents in 2010 to follow what we observed that year. Another advantage is that we can examine the artificial spatial distribution of SEPs across thousands of alternative samples. Thus, we can remeasure the concentration or diversity of these locations using the entropy formula or Gini coefficient.

Figure 7 displays the probability density function of entropy scores after we repeated this sampling process 1,000 times. For reference, we include the empirical estimates in dark red. The first row displays the distribution for the 3G period, while the second row shows the distribution for the 4G period. Each column represents a different method used to sample the H04 patents. In the first column, we present the distribution based on random sampling of the H04 patents without weighting by past SEP production. The second column weighs the sampling of H04 patents by the actual number of SEP applications. In column three, we save the predicted number of applications up to time *t* -- the values we obtain from running the stochastic process -- to predict future patenting at time *t + 1*. Finally, in the last column, we utilize the values from the 3G period to project the 4G period. Specifically, we apply the reinforcement process to estimate 4G production based on the 3G data.

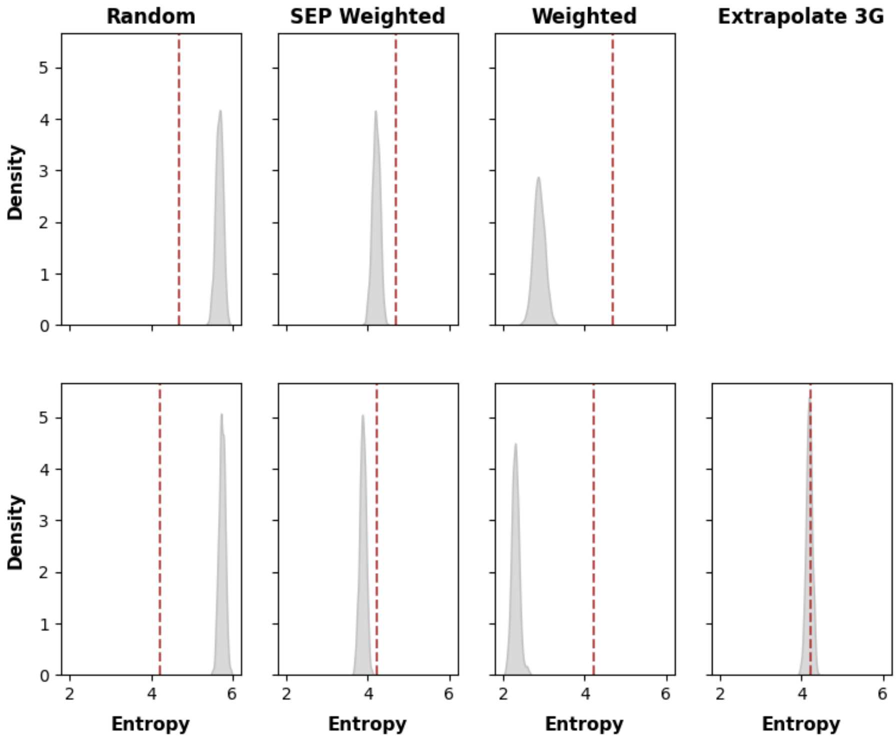

Figure 7: The figure shows six probability density functions of 1,000 entropy scores calculated after randomly sampling the yearly H04 patents according to different rules. The first row displays the distributions for the 3G period and the second the 4G. Column one uses an unweighted random process to sample the patents, column two uses the past SEP production as a weight, and column three uses the predicted number of applications for the years before. The final column uses the total number of SEP applications during the 3G period to sample patents in the 4G era. Each plot includes a red dashed line representing the estimated entropy values for the SEP distribution during these periods.

When we randomly sample the H04 patents, we underestimate the spatial concentration of SEPs. We should expect this result, as the estimated entropy derived from the random sampling tends to fall close to the actual observed H04 entropy -- which we have already established is significantly higher than that of the SEPs.

In contrast, the reinforcing process shown in column three over-represents this spatial clustering. When we weigh the sampling process at each time step by the results from the previous sample, we overestimate the share of patents produced by the leading region and the concentration of SEPs in space. Perhaps the winner-takes-all assumption is too strong, and we must leave room for others to catch up and challenge the leaders -- or at least they can also capture a small portion of the market.

Most likely, however, the initial distribution of SEPs among metropolitan regions in the year 2000, the starting point of the stochastic process, may not accurately reflect its future concentration. In other words, we misrepresent the market leaders at the onset, and the model exacerbates this error as we run through the reinforcing process. For instance, in 2001, Helsinki had only one SEP more than Eindhoven, so if we iterate the model using these values, we risk underrepresenting Helsinki's initial advantage.

In the appendix, we repeat the comparison between predicted and actual shares shown in Figure 6 using this sampling method (Appendix X). The outputs in the third column highlight the risk of overestimating the share of SEPs in Paris if we start sampling in 2001. Due to its size, Paris often leads Europe in patenting complex technologies. From the outset, without prior knowledge, it would be reasonable to expect this is also the case for the SEPs.

Along these lines, we might get more accurate results if we repeat this experiment using a later starting point, say 2007. Indeed, when we model the 4G distribution based on the accumulated 3G data, we achieve significantly better predictions, as shown in the fourth column. This contrasting result suggests that perhaps it's not apparent at first who will become the leader, but once one region takes the lead, the model does rather well at describing its continued success.

Furthermore, because of this continued success, the reinforcing model leads to the SEPs becoming more unevenly distributed in space as time progresses. Thus, it can accurately represent the observed drop in entropy from the 3G to the 4G period.

5.4 Helsinki Vs. Stockholm

The model that employs a reinforcing or autoregressive process accurately reproduces the spatial distribution of standard patents. However, it tends to overestimate the share of patents produced by Helsinki. Meanwhile, ignoring the autoregressive component misjudges the region's influence and biases our predictions. In summary, if we assume we can capture all the necessary knowledge to develop SEPs via the H04 output and use this to predict future SEP production, we overstate the size of the top H04 patenting regions, particularly Stockholm. Conversely, correcting our prediction by favoring places with a history of making SEPs to forecast future patenting can make us overrepresent Helsinki's lead.

These results suggest that the "rich get richer" analogy is valid, but they also indicate that the hold on this continued success is not as strong. One way to interpret this result is to represent it as one incumbent - Helsinki - and a challenger - the top H04 producer in Europe, Stockholm. There was no certainty that Helsinki would perform well, but once it took the lead, it was unlikely to lose it. On the other hand, Stockholm's specialization in H04 knowledge allows the region to take a minor share, compete, and potentially even overtake Helsinki in the future years as the top SEP-producing region in Europe. The increasing returns lead to a winner-take-all process where one region eventually dominates the market. But there is also room for breaking this rich-get-richer process, especially when a new generation comes along.

Focusing on these two cities helps visualize these dynamics. Figure 8 plots the number of H04 and SEPs produced by the top fifty regions in Europe between 2001 and 2016, where we highlight Stockholm in blue and Helsinki in red. We see a sharp rise in the total H04 output by Stockholm starting in 2001, leading it to become the largest producer starting in 2009 and continuing thereafter. This dynamic translates into more SEPs but is not sufficient to reach Helsinki. Nonetheless, towards the latter years in the sample, Stockholm experienced a faster growth rate, and its SEP production even passed Helsinki in the final year. So, maybe Stockholm's H04 knowledge is starting to pay off.

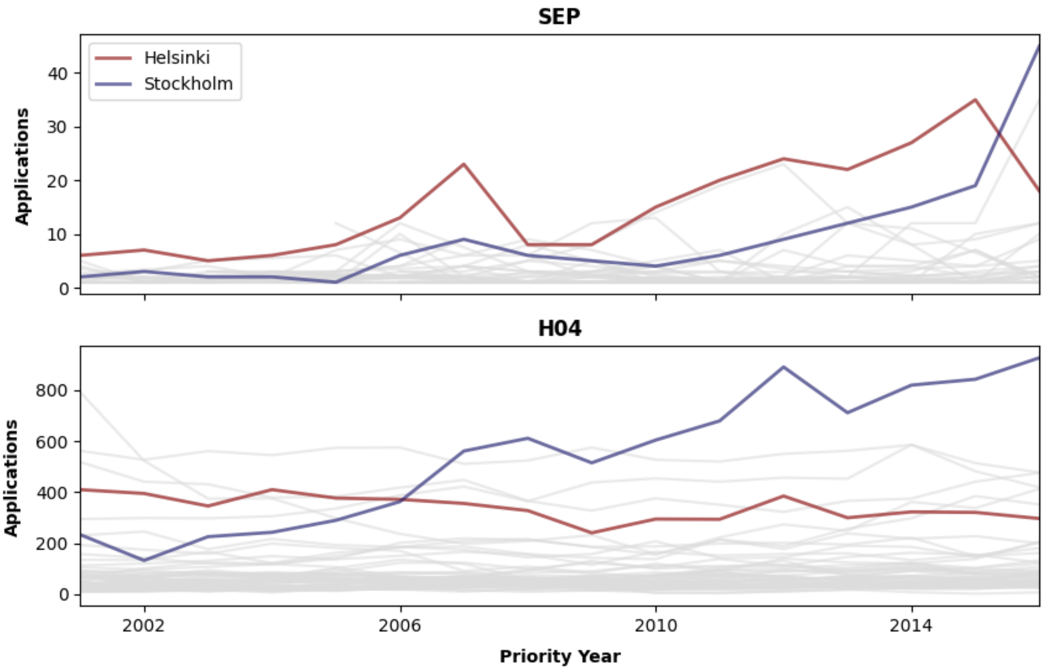

Figure 8: The first plot shows the number of SEP applications listing at least one inventor in the metropolitan area during that year. The bottom figure counts all H04 patents with at least one inventor in the area. We use the patents' priority year to count them. The graph includes the fifty regions with the most H04 patents through the sample, and we highlight the values for Helsinki and Stockholm.

We observe a similar trend if we use different metrics to represent the region's capacity to innovate and make wireless telecommunication technologies, like the share of citations to international sources or collaborations with inventors outside the EU (Appendix XI).

We also measured the similarity between the metropolitan's core knowledge in telecommunication and the frontier. For each region, we create a vector measuring the percentage of patents containing one of the 2,206 full-digit CPCs listed across all the SEPs. We repeat this for every priority year between 2001 and 2018. We also repeat this using a sample of all patents that do not list one inventor residing in the EU -- which will stand for the international knowledge frontier. Then, we measure the distance between these two distributions – the CPC shares in the metropolitan region and the global sample – using the Kullback–Leibler divergence:

$$\mathrm{KLD(P|Q)} = \sum_{\mathrm{i}}^{\mathrm{N}} \mathrm{p_i} \log\left(\frac{\mathrm{p_i}}{\mathrm{q_i}}\right)$$

where p_i is the share of patents in the CPC code “i” in the metropolitan area and q_i is the same share in the sample made of all international patents. If the share are identical for all CPCs, then the ratio between pi and qi is zero and KLD is also equal to zero. Yet the larger this difference – be it because ai or b – the larger the divergence.

Figure 9 displays the divergence between the CPC shares in the top 50 metropolitan regions with most H04 patents and the global sample from 2001 to 2016. We highlight the values for Helsinki (in red) and Stockholm (in blue). The two cities showed a similar trend until 2010 and 2011 when Helsinki's divergence score suddenly spiked and slowly returned to the same level as Stockholm's in the final years. Indeed, the graph exhibits that most metropolitan areas observed a similar bump right around the time 4G came along. Stockholm is one of the few notable exceptions. While we can only speculate, perhaps these outputs demonstrate that not all metropolitan areas had the related knowledge necessary to adopt and develop the standards introduced during the 4G era.

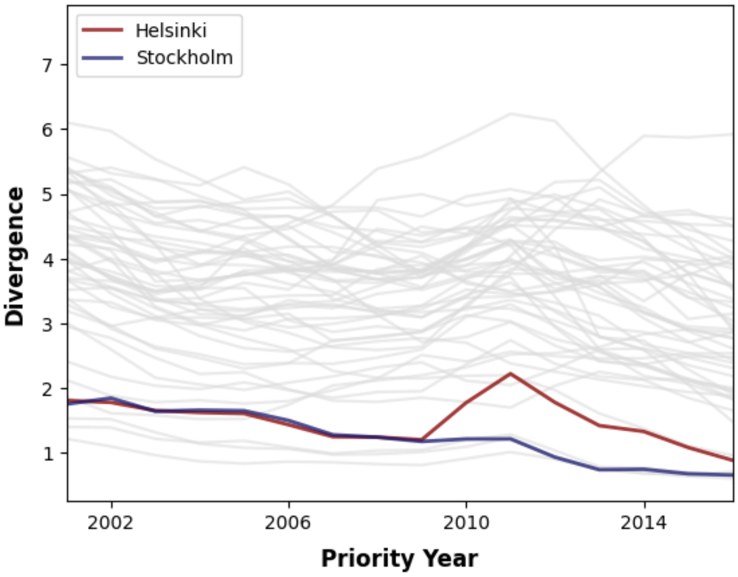

Figure 9: The y-axis displays the Kullback-Leibler divergence between the share of CPCs in the metropolitan area and the shares of CPCs among the patents that do not list one EU inventor.

All plots tell a similar story. Stockholm slowly becomes a leading producer of H04 in Europe. Thus, it can challenge Helsinki's dominion of SEP. On the other hand, while the top producer during the 3G era, perhaps Helsinki could not easily transition to the new generation[23].

6. Discussion and Concluding Remarks

A substantial literature utilizes patent data to analyze and map the spatial distribution of technological innovation. Some studies take a broad approach by examining the relative shares of patent codes produced in each region to understand the forces driving diversification and specialization (Boschma et al., 2015; Kogler et al., 2013; 2017). Others offer a more focused

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[23] The timing of these shifts matches the introduction of 3G and 4G in Europe. But it does also match the merger between Sony and Eriksson (2001) and the subsequent acquisition of the Swedish shares by the Japanese firm (2012). Could these results be driven by this merger instead? It's hard to separate the two as the decision to acquire Eriksson by Sony was driven by the new 3G/4G market, too. But it seems that the production of SEP patents by the two firms follow a similar trend.

perspective, investigating the geographical distribution of patents within specific general-purpose technologies such as nanotechnology, recombinant DNA, or artificial intelligence (Calignano et al., 2024; Feldman et al., 2015; Buarque et al., 2020). Together, these past efforts yield valuable insights into regional development and further validate and expand some of the well-known stylized facts in the geography of innovation (Feldman and Kogler, 2010, Malecki, 2021).

Nonetheless, one size does not fit all, and perhaps some observed patterns might depend on the nature of the technology under study. For instance, technologies used for wireless transmission require all users to adopt the same standard to ensure optimal communication. These technologies are subject to positive feedback and increasing returns, meaning that the more people adopt a particular standard, the greater the benefits for those who follow suit. This results in a well-documented winner-takes-all process, which can influence how these technologies are distributed geographically.

In contrast to general-purpose technologies that can be combined and recombined with other fields, standard-based technologies often face intense competition, leading to a more pronounced concentration of patterns due to strong reinforcement. As a result, this may create a distinctly uneven geographical distribution. However, we still lack robust empirical evidence regarding the distribution of technological standards to validate this assumption.

While we have limited evidence on the spatial distribution of technological standards, ample theoretical and empirical work seeks to describe the winner-takes-all dynamic process behind it. From a modeling perspective, game theory provides a powerful tool to describe the competition between technological standards as a coordination problem. Hence, past literature used this approach to examine the lock-in process, where some methods can take the lead at the early stages due to some initial advantage and will remain the standard due to reinforcement even after this initial advantage is gone (Arthur, 1989; Henrich, 2018). Likewise, building on this idea, empirical work leveraged data from patents to demonstrate the reinforcing dynamics in the popularity of competing standards like HD-DVD and Blu-ray, PC operating systems, or wireless telecommunication (Kim et al., 2017; Cho et al., 2021). However, to our knowledge, no previous research examined the spatial implications of these dynamics. In other words, we should expect these lock-in and winner-takes-all processes to manifest in the geographical distribution of where these standards are produced. We should expect that at least some stylized facts about the geography of innovation will differ in the presence of the reinforcing process, leading to even greater concentration and adherence to one region and one standard. This is the gap we aim to explore.

We collected data on 1,397 standard essential patents (SEPs) related to mobile telecommunications, with at least one inventor residing in Europe, from ETSI. Using the inventors' addresses, we assigned these patents to metropolitan regions. We plotted these locations to identify the top SEP-producing areas in the continent and assess the spatial concentration of these patents. Our findings reveal a heavy concentration in space, with two regions representing nearly 33% of all patents -- Helsinki and Stockholm. Additionally, this concentration is significantly more pronounced than one might expect compared to other complex technologies, as identified by their CPC codes. This includes the H04 class covering all electric communication technique patents, which 99% of the SEPs belong to. We also find that this distribution does not sale superlinearly with population size nor can we explain it solely using the region’s past H04 knowledge production, as might be anticipated based on existing evidence in the field. These results highlight the importance of considering different types of technologies when modeling their spatial distribution. Furthermore, they illustrate some consequences of the winner-takes-all process driving technological standards previously overlooked in the literature.

By the same token, compared to previous empirical research on the popularity of adoption between two standard alternatives, our data coverage allows us to measure the uneven geography of several standard essential patents for two generations. Kim et al. (2017) studied the competition between HD-DVD and Blu-ray, which can be seen as part of a longer video "format war" dating back to the VHS and Betamax competition. Similarly, Cho et al. (2022) focused on two standards used in the fourth generation of wireless telecommunications, potentially overlooking longer-term trends originating from the third generation and earlier. For their research, this shorter interval might not have significant implications, but when we focus on the dynamics of industries, firms, or regions producing and endorsing these subsequent format wars, the long trends might matter.

Along these lines, we observe that Stockholm becomes the lead producer of H04 patents and later uses this position to challenge Helsinki's dominance in SEP production during the 4G period. Our observations show that Helsinki can retain its SEP status during the later years of the sample. So, its initial advantage persists in the next generations, as we expect from the winner-takes-all reinforcement process described above. Yet, the new generation allows Stockholm to catch up and compete with Helsinki. Perhaps the increasing returns lose some of their strength when we shift to the next generation of technologies. We can observe this after we predict the number of SEPs in each generation using the results from a zero-inflated negative binomial. When we use only the H04 production to estimate the count of SEPs, the model significantly overestimates the size of Stockholm output during the 4G period. Yet, when we add an autoregressive factor and bring the previous SEP production into the analysis, the model overestimates Helsinki's shares. The reality is somewhere in the middle, where the increasing returns ensure Helsinki maintains its position. But it also weakens with time and allows the top H04 producer to challenge. In light of this result, one could model the "format wars" as a series of subsequent coordination games where new technologies introduce a new competition between the standards, partially resetting the stage.

These results provide valuable insights into the upcoming dynamics of 5G and potentially beyond. The ETSI data coverage does not allow us to measure the last years of the 4G period or the beginning of the new generation. Consequently, this data does not provide much information to forecast the geographical distribution of standards during the 5G era. However, we do have data on H04 production worldwide, which, when coupled with the findings of this paper, could help us envision future developments.

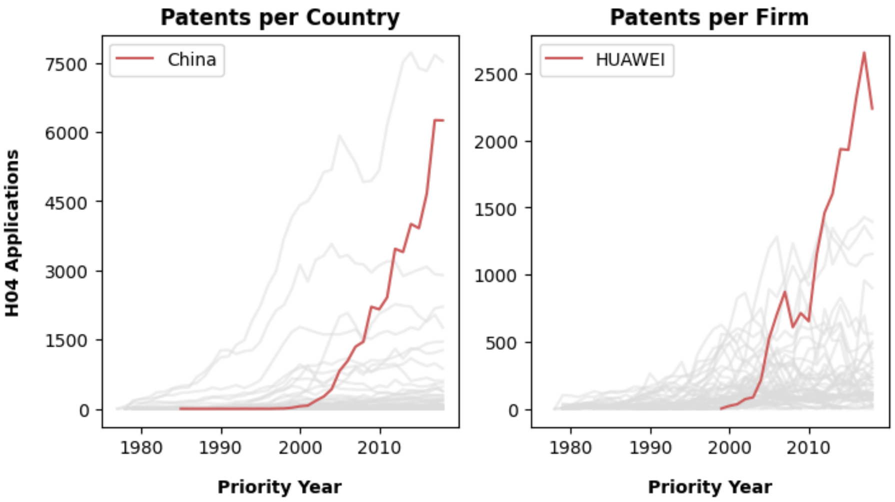
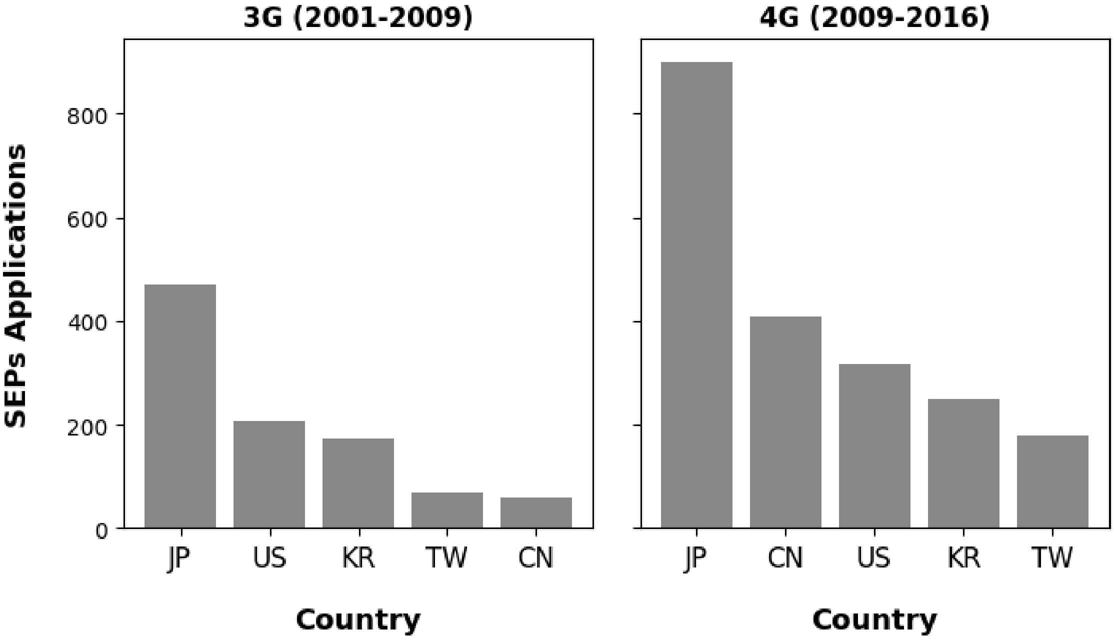


Figure 10: Plots the number of patents per year by country and firm. We use the priority year and sum up all patents that list either one inventor living in the country or the firm as the assignee.

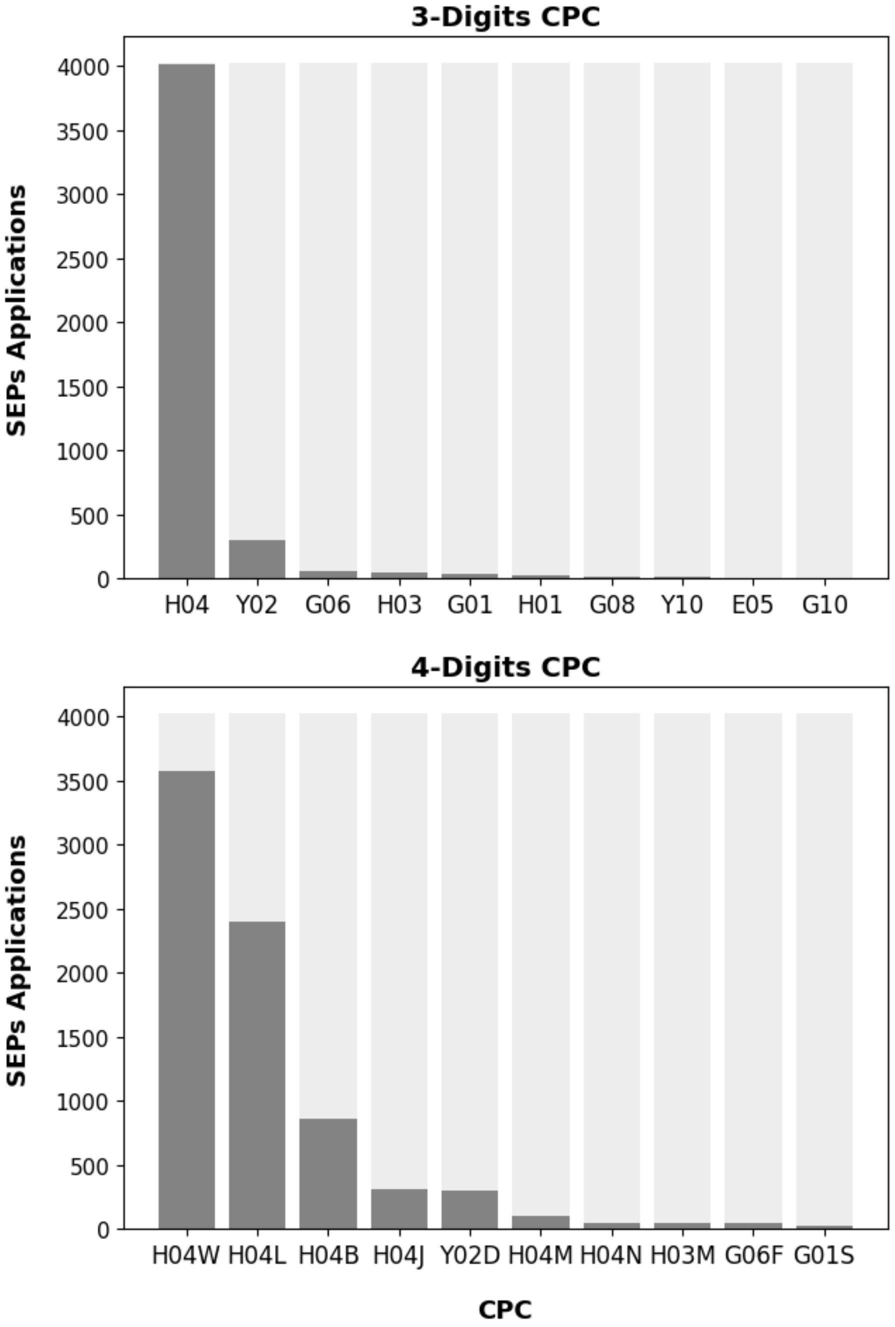
Figure 10 illustrates the yearly SEP production by country and firm, with trends for China and the Chinese multinational conglomerate Huawei highlighted in red. This situation resembles what we observed when Stockholm emerged as the leading H04 producer before challenging Helsinki during the 4G period. We are left wondering whether this pattern will repeat. In other words, as we enter the 5G era, will China's dominance in telecommunications be enough to establish its standards, or will the existing forces of global standardization continue to set the agenda from the outset? Although this narrative is primarily descriptive, it can help us address this question.

Appendix

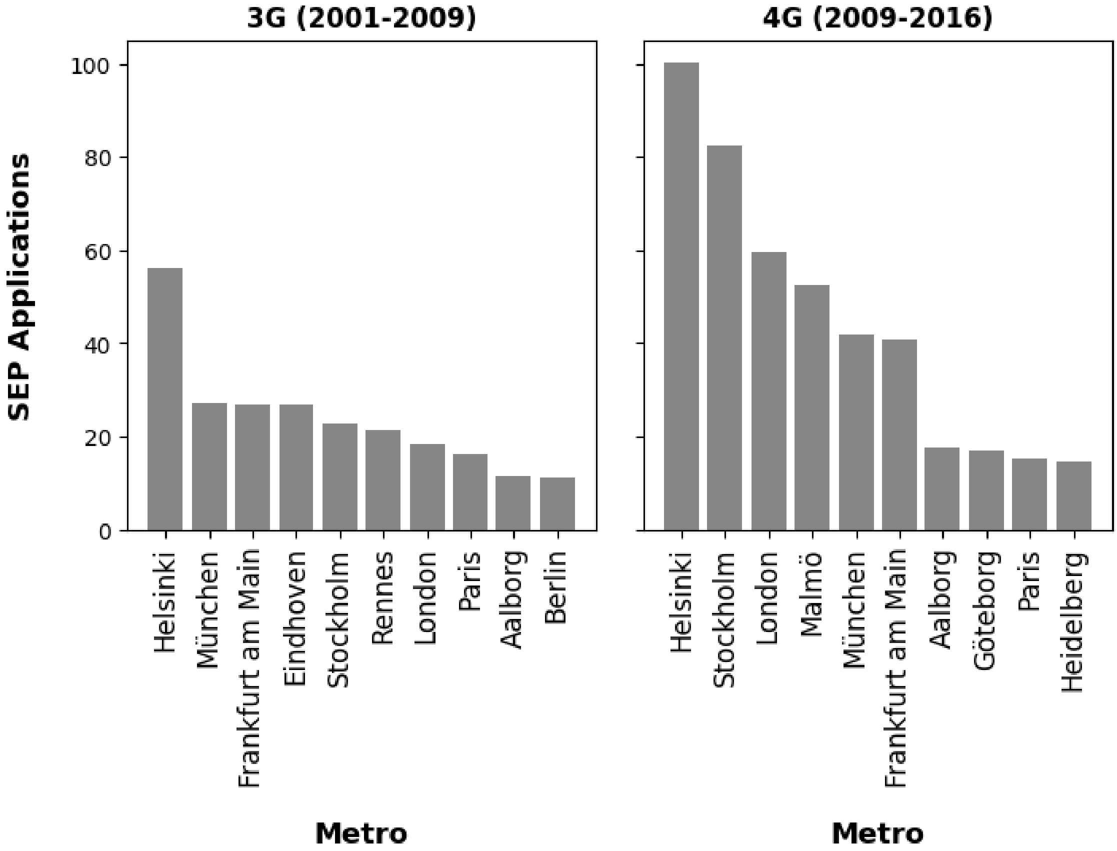
APPENDIX I: Number of SEPs by Inventor's Country



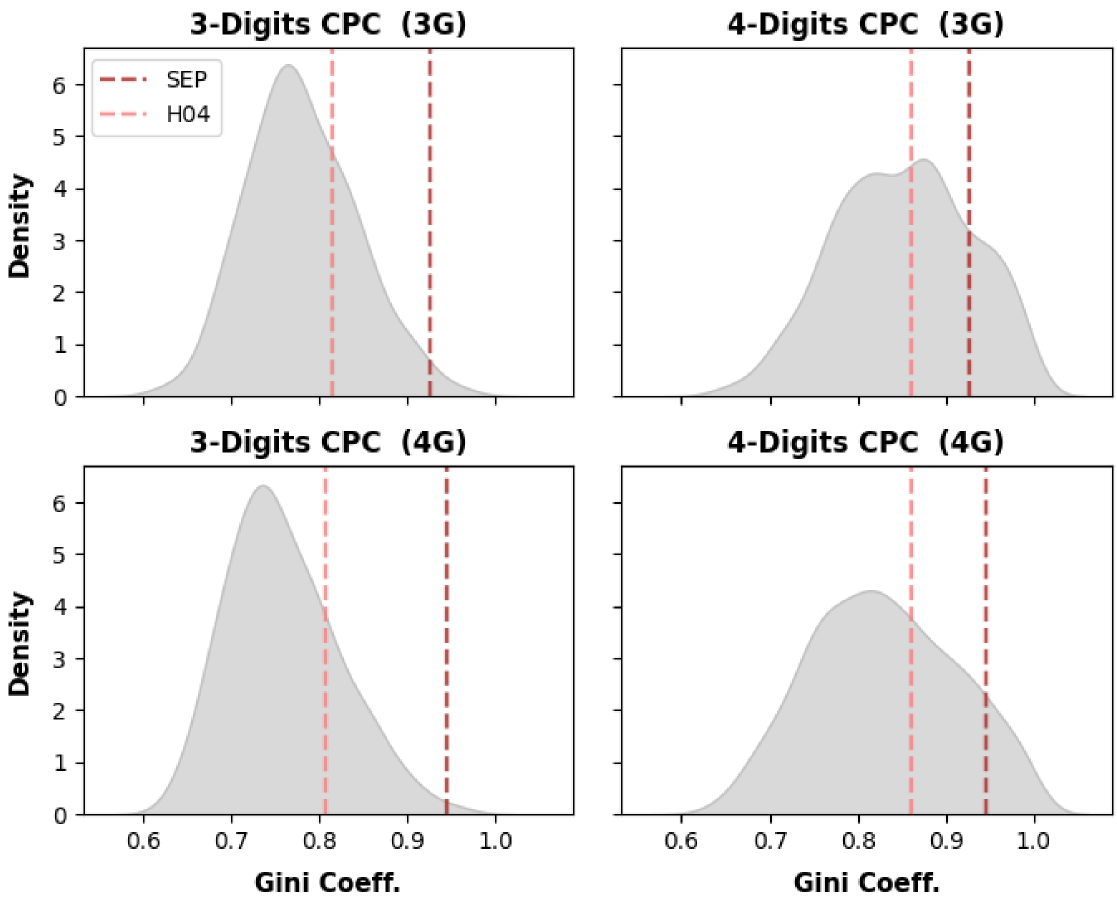
APPENDIX II: Number of SEPs by CPC



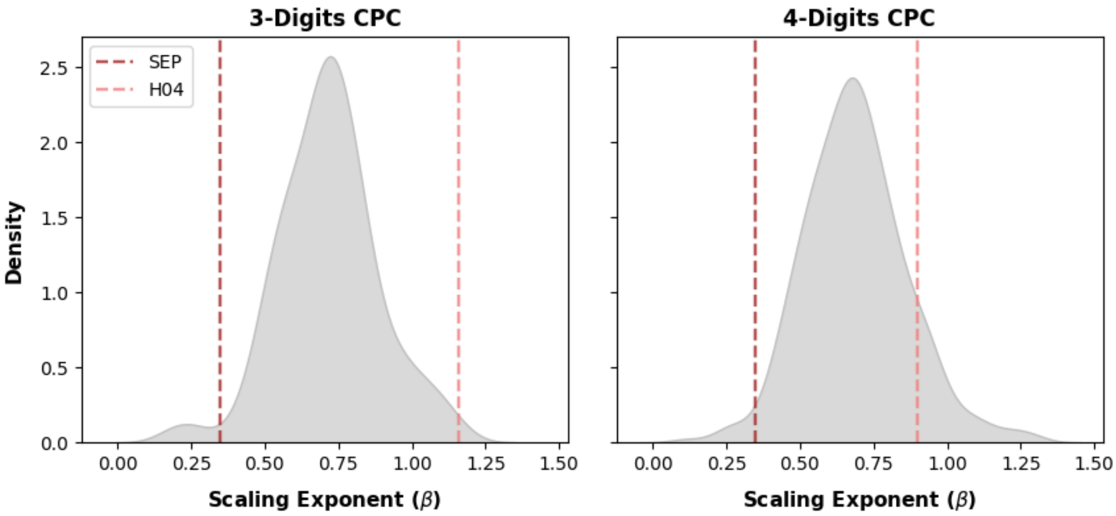
APPENDIX III: Relative Shares of Patents per Metropolitan Area



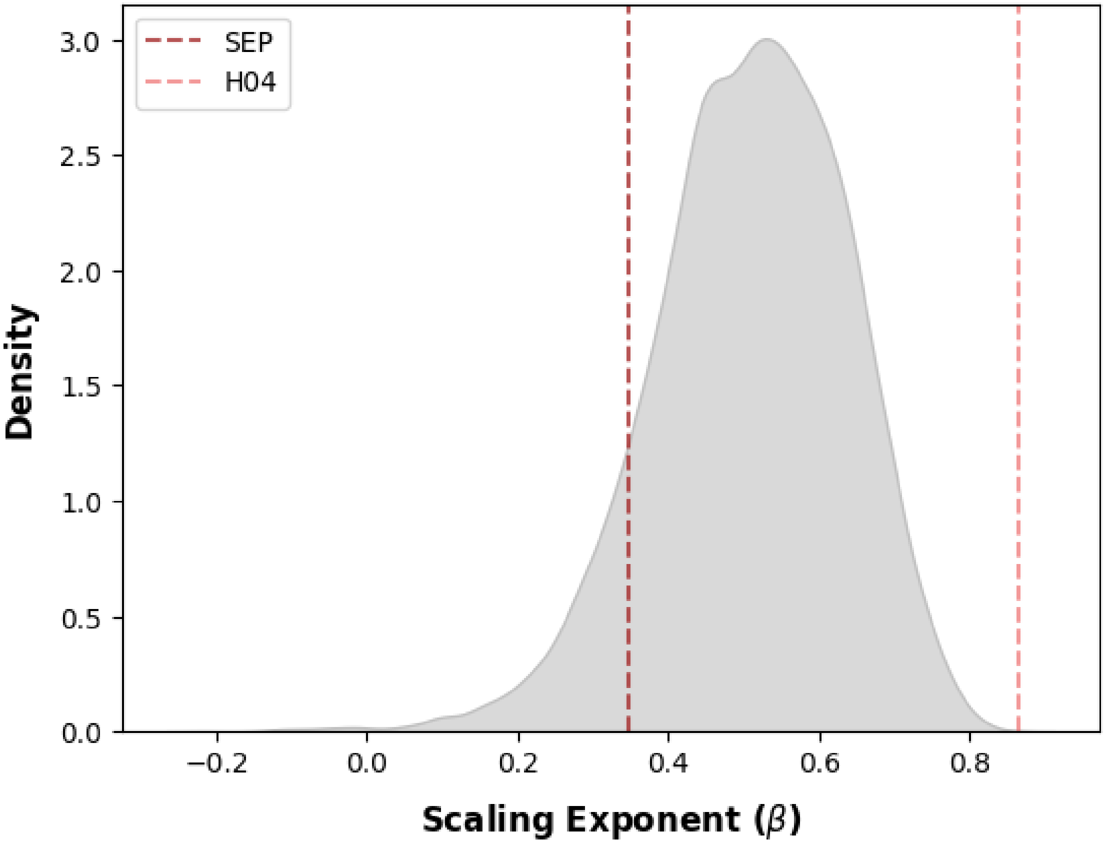
APPENDIX IV: SEP Spatial Concentration (Gini Coefficient)



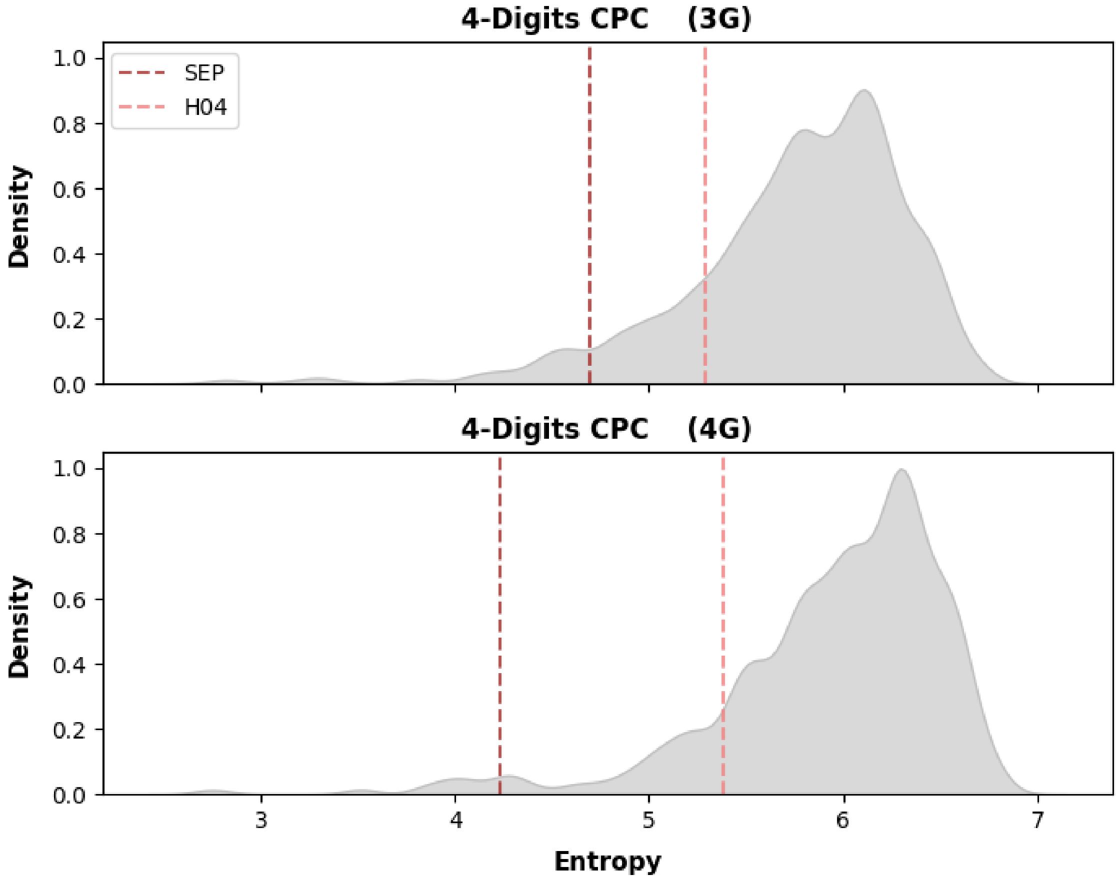
APPENDIX V: Density Distribution of the Beta Coefficient



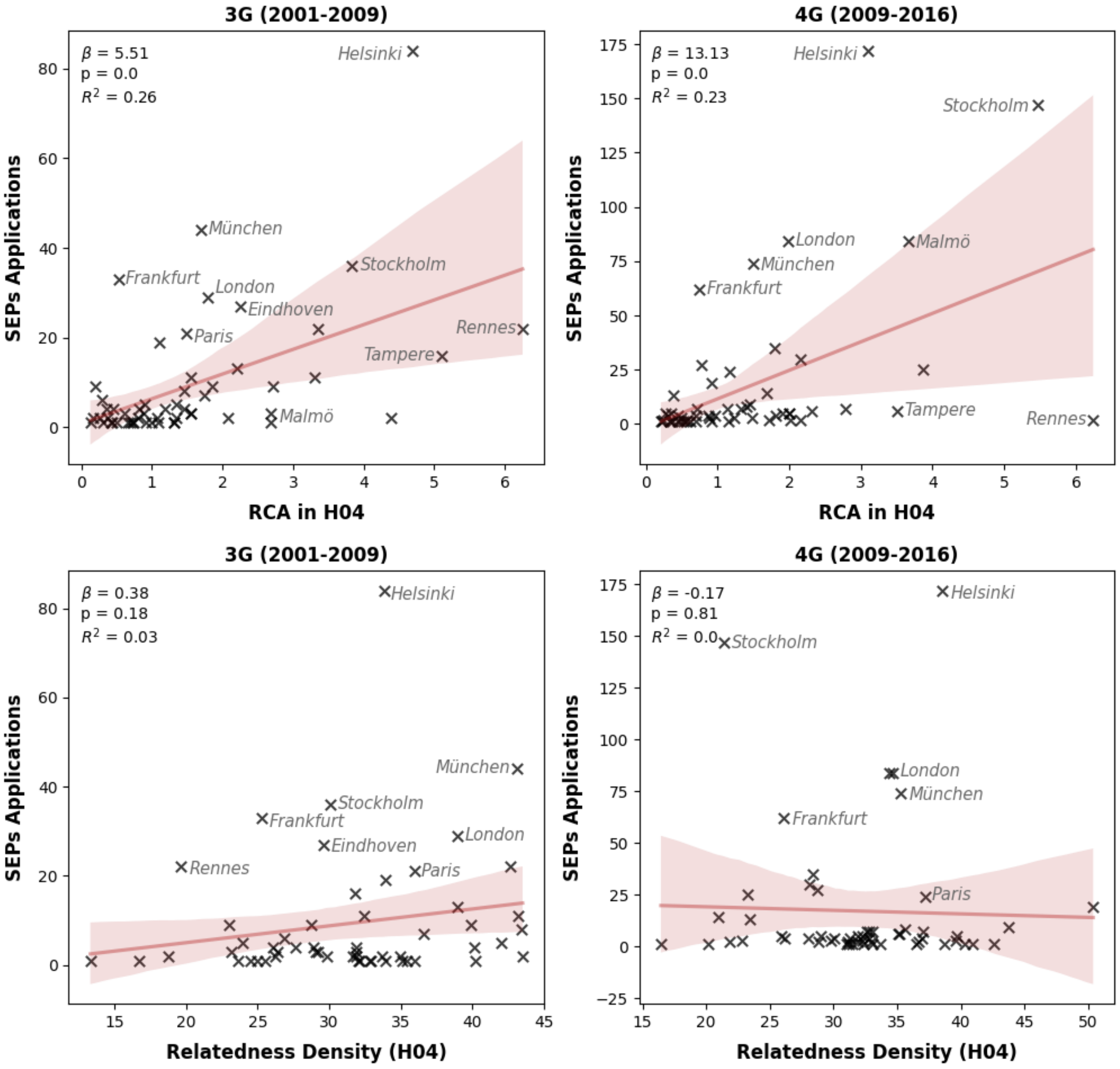
APPENDIX VI: Density Distribution After Sampling 1,000 patents of each CPC



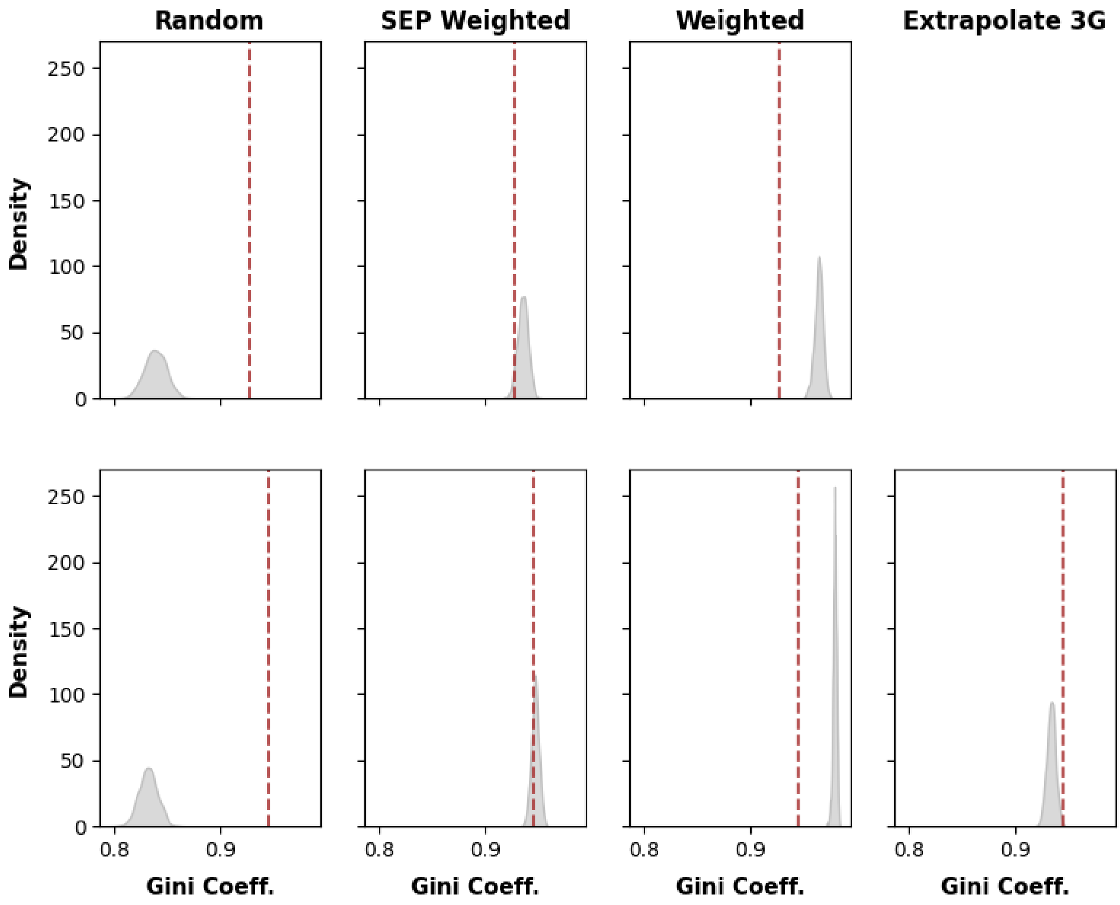
APPENDIX VII: SEP Geographical Concentration after sampling 1,000 patents per CPC



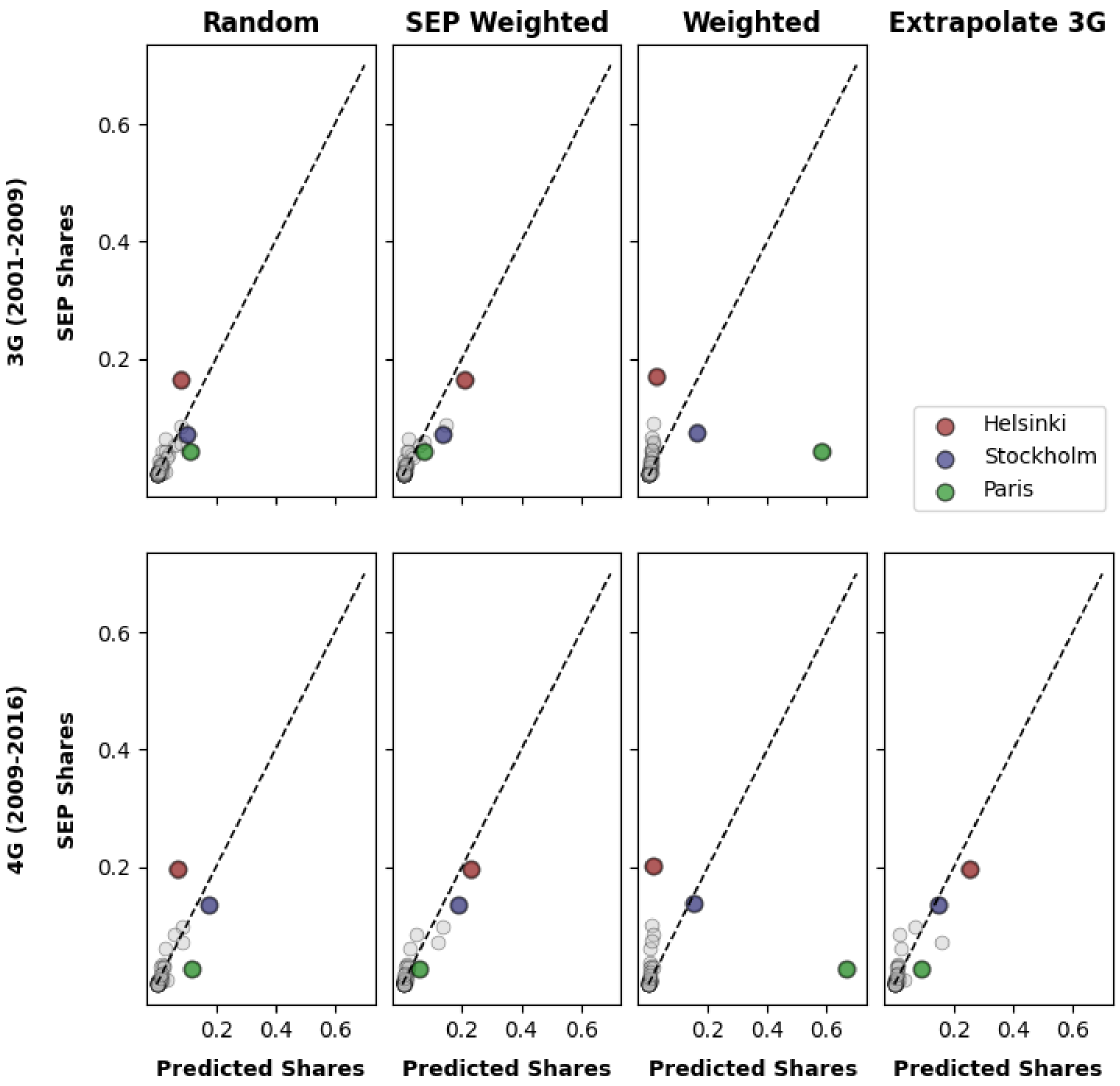
APPENDIX VIII: Relationship between SEP and H04 knowledge



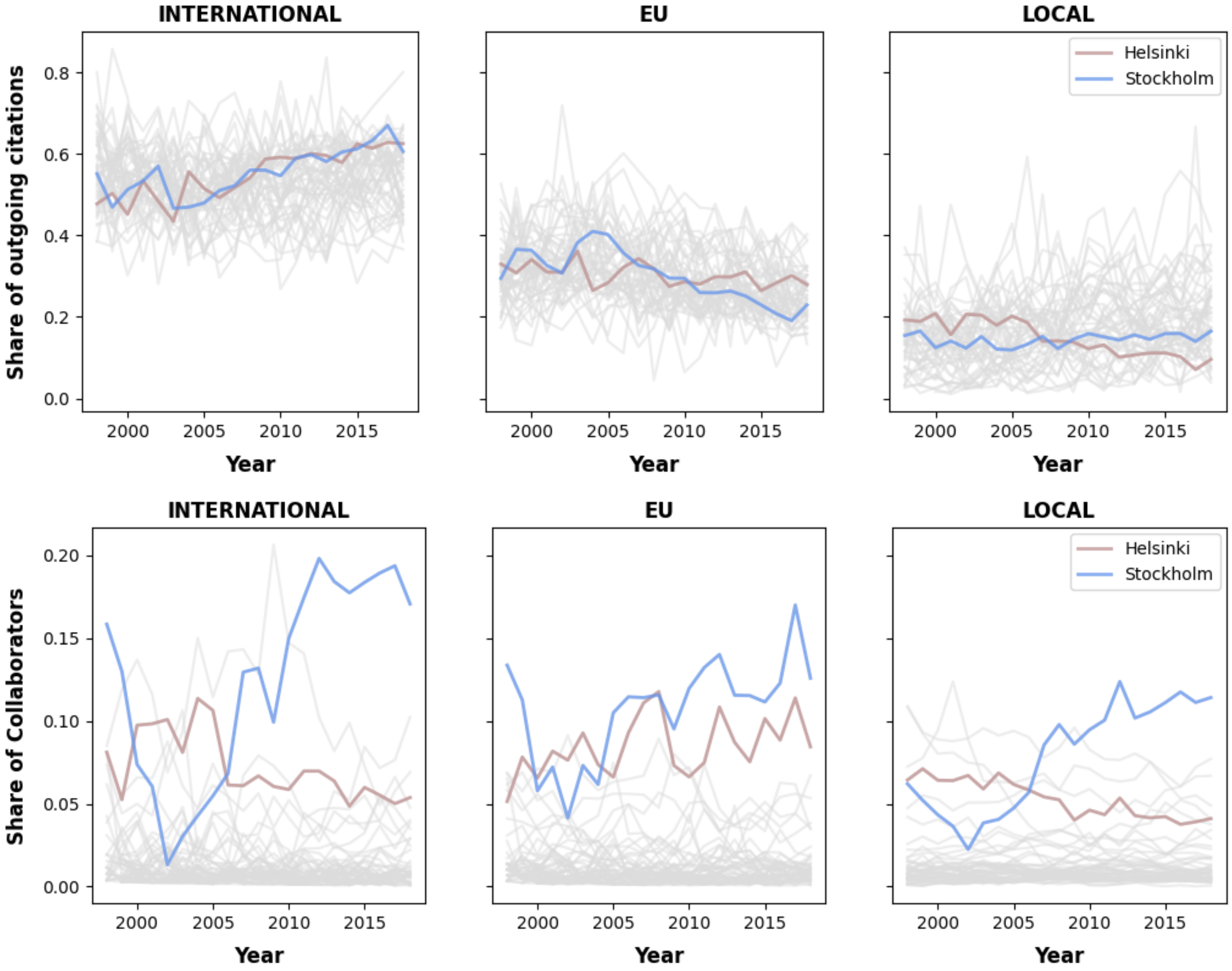
APPENDIX IX: Density Distribution of 1,000 random Gini Coefficients



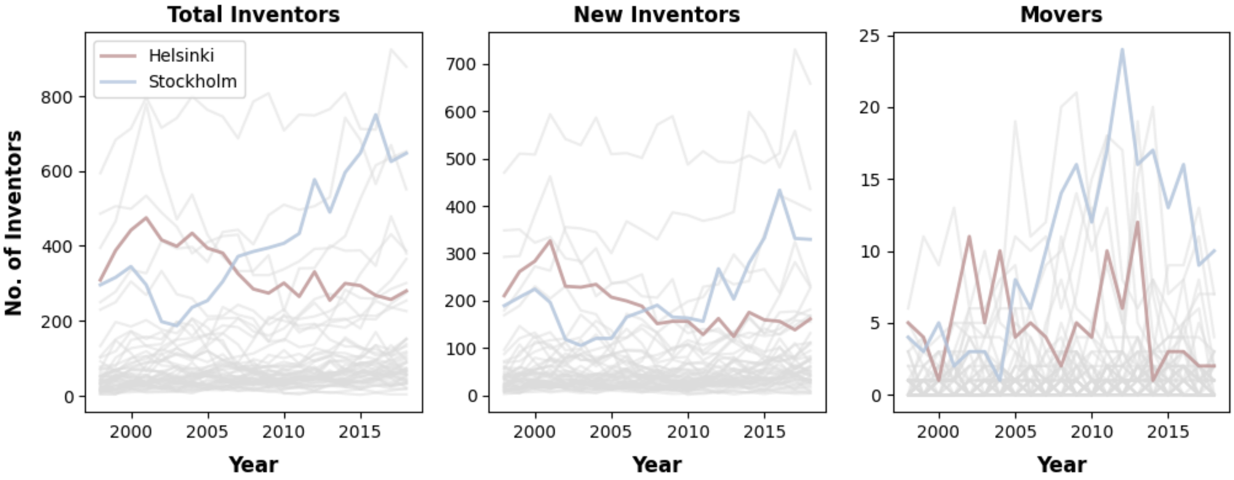
APPENDIX X: Average Prediction vs. Actual Values



APPENDIX XI: Share of citations and collaborations by origin



APPENDIX XII: H04 Inventors by Metro



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