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Is innovation (increasingly) concentrated in large cities? An international comparison

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Is innovation (increasingly) concentrated in large cities? An international comparison

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Abstract

We investigate the geographic concentration of patenting in large cities using a sample of 14 developed countries. There is wide dispersion of the share of patented inventions in large metropolitan areas. South Korea and the US are two extreme outliers where patenting is highly concentrated in large cities. We do not find any general trend that there is a geographic concentration of patents for the period 2000-2014. There is also no general trend that inventors in large cities have more patents than in rural areas (scaling). Hence, while agglomeration economies of large cities may offer advantages for innovation activities, the extent of these advantages is not very large. We conclude that popular theories over-emphasize the importance of large cities for innovation activities.

JEL-classification: 031, R12, O57

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1. Introduction: Large cities and innovation[1]

Large cities appear to have many advantages over rural areas, one such advantage is commonly known as agglomeration economies (Duranton and Puga 2004; Glaeser 2011; Jacobs 1969). Based on claims about the effectiveness of agglomeration economies, many scholars argue that large cities are 'innovation machines' and that agglomeration economies are a requirement for successful innovation activity (Carlino and Kerr 2015; Florida, Adler and Mellander 2017). Some scholars go so far as to take this widespread belief that innovation activities are considerably more successful and productive in large cities to suggest that policy attempts to stimulate innovation in non-urban areas are ineffective and a waste of resources (see, for example, Glaeser and Hausman 2019).

This paper investigates and compares the geographic concentration of patents in a number of developed market economies. We find a wide dispersion of the share of patenting in large metropolitan areas among the countries of our sample. While South Korea and the US are two 'outliers' with an extremely high concentration of patents in some large metropolitan areas, this type of concentration is much less pronounced in the other countries of our sample. Moreover, it is often not the largest metropolitan areas that have the highest shares of patents. A further important finding is that inventors in large metropolitan areas do not have more patents than inventors located in non-urban areas. We do not find a general trend of increasing geographic concentration of patents over the 2000-2014 period. In fact, there are more countries where the concentration of patents in large metropolitan areas is decreasing than countries where this type of concentration has increased.

Our results challenge the belief that innovative activity occurs mostly in large cities (Florida, Adler and Mellander 2017). We argue that empirical evidence of regional innovative activity based on the rather

[1] We are indebted to Maria Kristalova, Frank Neffke, and Korneliusz Pylak for helpful comments on an earlier version of this paper.

special case of the US should be regarded with great caution. It seems obvious that drawing generalizations based on evidence from a single country may not be valid for other countries. Such generalizations may ignore other important factors or economic realities that exist in other countries. Based on the results of our research, we conclude that agglomeration economies are much less important for innovation activities as is suggested by some popular theories.

The paper is structured as follows. The next section (Section 2) provides an overview of the arguments for the claim that large cities are a prerequisite for successful innovation activity. Section 3 introduces the data and the definition of spatial categories employed in our research. We then compare the shares of patents in different spatial categories (Section 4), and analyze geographic concentrations in general (Section 5). Section 6 summarizes our findings and discusses the outcomes, offers some thoughts about theory and policy, and outlines some important avenues for further research.

2. Why successful innovation activity might occur mostly in large cities

Empirical research suggests that innovation activity is geographically concentrated in large cities than population or the general production of goods and services (Feldman and Kogler 2010; Bettencourt, Lobo and Strumsky 2007; Carlino and Kerr 2015). The common interpretation of this result is that large cities have a locational advantage with regard to innovation activity over less densely populated areas (Glaeser 2011; Glaeser and Hausman 2019). To test this hypothesis, some authors regress the number of patents on the regional population, or the number of inventors in a region.[2] These studies find that larger cities tend to have more patents per population than smaller cities. This effect of 'urban

[2] Bettencourt, Lobo and Strumsky (2007), Bettencourt and Lobo (2016), Bettencourt (2013), Gomez-Lievano, Patterson-Lomba and Hausmann (2017).

scaling' is obviously due to the fact that larger cities also tend to have a higher share of inventors.

A common explanation for higher levels of innovative activity in large cities builds on the effect of agglomeration economies. Literature mentions four reasons why large cities may be favorable places for innovative activity (see Duranton and Puga 2004; Puga 2010; Carlino and Kerr 2015), particularly when compared to rural or peripheral regions.

- *First*, large cities tend to have a rich endowment of R&D facilities (such as universities, other public research institutes), and innovative private sector firms ('sharing').
- *Second*, large cities have abundant input markets that stimulate R&D that provide a better and more productive match of inputs ('matching') (Helsley and Strange 2002, 2011).
- *Third*, the rich endowment of R&D facilities found in large cities provide more knowledge spillovers due to the spatial proximity and cooperation of R&D actors ('learning').[3]
- *Fourth*, Large cities may be highly attractive places for creative people (Florida 2002; Florida, Adler and Mellander 2017). In this way, large cities benefit from inflows of talent and new knowledge from other areas that strengthens the quality of the regional workforce there. This redistribution of talent comes at the expense of other areas.

Although these advantages of large cities (Bettencourt 2013) are undisputed, cities also have diseconomies such as high levels of crime, pollution, traffic congestion etc. Moreover, the relatively easy flow of knowledge that occurs within cities may be considered a disadvantage for firms that want to keep their knowledge secret.

What is still rather unclear is how the disadvantages and other potentially negative factors of agglomerations impact its assets. While some scholars assume that the agglomeration advantages are rather

[3] Bettencourt, Lobo and Strumsky (2007), Breschi and Lenzi (2006).

dominant,[4] others are more cautious in this respect. One important objection against the simple ‘innovation requires large cities’ argument is that cities should not be considered in isolation, but rather in the context of the whole spatial system of a set of locations. In other words, large cities rarely exist in spatial isolation. Instead, large cities spatially exist and interact with smaller cities and less populated areas, and the geographic distances of the spatial system introduce important idiosyncrasies (Crescenzi, Rodriguez-Posé and Storper 2007; Bettencourt and Lobo 2016). If distances between cities are relatively small—as is the case in many parts of Europe—division of innovative labor between cities and inter-agglomeration spillovers may be much more pronounced than in a constellation where geographic distances between the main agglomerations are rather large, as is the case in the US.[5]

A frequently heard argument promoting large cities is their higher productivity (Ciccone and Hall 1996; Ciccone 2000) that is reflected in higher wages, the so-called ‘urban wage premium’.[6] This is, however, of limited relevance for innovation activity because higher productivity is a static phenomenon while innovation is an inherently dynamic process. Hence, for successful innovation it is particularly important that places are able to manage and adapt to change. We are not aware of any study that provides robust empirical evidence of higher productivity of innovative activity in larger cities.[7] There are, however, quite a number of examples of economic success taking place in larger cities that did not persist when

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[4] For example, Florida, Adler, and Mellander (2017, 93) state that “…innovation and entrepreneurship do not simply take place in but *require* cities.”

[5] As a consequence, Crescenzi, Rodriguez-Posé, and Storper (2007, 686f.) speculate that “the higher average population density of the EU, with major metropolitan areas relatively closer together than in the US (where instead metropolitan areas are farther away from one another), may allow a more intensive Continent-wide circulation of knowledge, and possibly limit the distance decay of useful knowledge”.

[6] Carlino and Kerr (2015), Faberman and Freedman (2016), Glaeser and Maré (2001), Puga (2010), Neffke (2017).

[7] Moretti (2019), in a recent analysis for the USA, distinguishes a number of technological fields and finds that the number of patents per inventor in a certain field increases with the size of the cluster (not city size) measured as the number of regional inventors that have patents in the respective field.

the given products and technologies mature and are replaced by new and more relevant fields of knowledge (Storper 2018).[8]

It is quite remarkable that many studies of the relationship between innovation and city-size disregard rural areas and, therefore, cannot make comparisons between cities and non-agglomerated areas. Despite this, there are a few studies that focus on successfully innovating firms in rural and peripheral areas.[9]

Research on regional innovative activity has identified many factors other than city size and settlement structure that may be relevant for regional innovation activities. These other influences include: institutional conditions, the population's age structure, the sectoral composition of the local economy and the type of knowledge base, the quantity and the quality of the available human and social capital, as well as regional and national cultures (Asheim, Isaksen and Trippl 2019; Crescenzi and Rodriguez-Posé 2013; Fritsch and Slavtchev 2011).

3. Data and definitions

3.1 Patents as an indicator for innovation activities

Patents is the only available indicator for innovation activity that allows for a comparison of the geographic structure across a larger number of countries. Although a patent represents an invention and not its application in a new process or product, it indicates an intermediate result of innovation effort.

Patents as innovation indicator have a number of advantages and disadvantages (for an overview see Griliches 1990, and Nagaoka, Motohashi and Goto 2010). A main advantage of patents is that obtaining a patent requires a certain level of 'newness' that secures comparability across countries and regions. The patent data include considerable

[8] Well-known examples are old industrialized areas such as the German Ruhr area, Detroit in the US, or Glasgow in Scotland.

[9] E.g., Fritsch and Wyrwich (2020), Graffenberger et al. (2019), Grillitsch and Nilsson (2015).

information, such as: the technological field according to the International Patent Classification, the date of application, name(s) and address(es) of the applicant(s) as well as name and address of each of the inventors. Patents are taken from the OECD regional patent database (RegPat) and are assigned to the region in which the inventor claims his or her residence. If a patent has more than one inventor, the count is divided by the number of inventors and each inventor is assigned his or her share of that patent.

Using patents as a measure of economic activity may have some shortcomings. One disadvantage of patents can be seen in the fact that they represent only the first stage of an innovation process. Hence, one does not know if or where the invention will become a marketable product market novelty (Feldman and Kogler 2010). There is also a clear indication that the economic value of patents considerably varies, indicating that their economic impact is unpredictable.[10] Another critical issue is that not all firms or inventors use patents as a way to protect their intellectual property (Cohen, Nelson and Walsh 2000; Blind et al. 2006). Hence, not all inventions are patented. Moreover, some inventors obtain a number of related patents for basically the same invention in order to block follow-up patents by rivals.

3.2 Sample

For an international comparison of the spatial concentration of patenting activity across countries, we not only include the G7 countries,[11] but also consider some other highly developed countries, namely: Sweden, South Korea, Switzerland, and Spain. Finally, we also include the Czech Republic, Poland, and Hungary as examples of post-socialist transition countries. We assume that Sweden and South Korea will reveal a pronounced geographic concentration of innovative activities due to the

[10] The distribution of the economic value of patents appears to be highly skewed. While a few patents are extremely valuable, most patents are not worth much (Harhoff, Narin, Scherer and Vopel 1999; Harhoff, Scherer and Vopel 2003).

[11] The G7 countries are Canada, France, Germany, the United Kingdom, Italy, Japan, and the US.

high share of the population of these two countries in and around their capital cities, Stockholm and Seoul. The same is to be expected, although to a somewhat lesser degree, for the United Kingdom (Greater London), France (Paris/Ile-de-France), Hungary (Budapest), and Japan, where population is concentrated mainly in the metropolitan areas of Tokyo and Osaka.

The US is geographically much larger than the European countries, with a considerably lower population density and higher geographic concentration of population in large cities. Accordingly, innovative activity in the US may be strongly clustered in some regions as well. Another characteristic of the US is the relatively greater distances between large metropolitan areas that may work as an impediment to an inter-regional division of innovative labor (Crescenzi, Rodriguez-Posé and Storper 2007). Germany, Italy, Spain, and Switzerland are characterized by decentralized political and economic structures caused by historical developments.

There are considerable differences with regard to the number of patents per 10,000 population between the countries of or our sample (see Table A2). Switzerland, Sweden, Japan, Germany and South Korea have the highest rates, followed with some distance by the US. The lowest rates are found for the three former socialist countries of Eastern Europe Poland, Hungary and the Czech Republic.

3.3 Regional categories

In our analysis we follow the OECD definition of functional urban areas (OECD 2012). These areas are geographic units characterized by one or more cities (the core) and a commuting zone that is interconnected with the city. A city is a local administrative unit where at least 50% of its population live in an urban center. An urban center is defined as an area with a density of at least 1,500 population per km^2, and an overall population of at least 50,000. The commuting zone is defined by local administrative units for which at least 15% of the workforce commute to the city. Commuting zones of the functional areas are identified based on commuting data (travel from home-to-work). In the assessment, we distinguish between large metropolitan areas (population >1.5 million), metropolitan areas (population = 250,000 to 1.5 million), non-metropolitan areas (population <250,000), and regions that are not part of a functional urban area.[12]

The official OECD definition of functional urban areas does not exactly resemble the borders defined by official statistical areas (TL3 regions) for which our patent data are available. Therefore, we include TL3 regions (NUTS3 regions in European Union countries) as part of functional urban areas if the bulk share of the TL3 region is part of the commuting zone of the urban center. Since it might be the case that NUTS3 regions host a metropolitan area and some smaller parts of non-metropolitan space, we may slightly overestimate the patent share of (large) metropolitan areas. TL3 regions are also used in our regression analysis of urban scaling patterns (Section 4.4) where we apply the same logic. Table A1 in the Appendix displays the number of regions in the different spatial categories per country of our sample.[13]

4. The spatial structure of innovative activity across countries

4.1 Metropolitan and non-metropolitan areas

We first investigate the contribution of a country's large metropolitan areas to the national share of patents (Table 1).[14] The motivation for taking this

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[12] In their analysis, Paunov et al. (2019) define all functional urban areas as "cities" while our focus is on functional urban areas that the OECD defines as metropolitan areas or large metropolitan areas. In contrast to our approach, their analysis also does not consider regions that are not part of a functional urban areas in.

[13] It should be noted that the size and number of TL3 regions differs across countries. Hence, in countries where TL3 regions are relatively large, metropolitan areas can comprise larger parts of surrounding area than in countries where TL3 regions are smaller, making the definition less precise. As a consequence, our data has a slight tendency of assigning more patents to metropolitan areas in countries with larger TL3 regions.

[14] Switzerland has to be excluded from this analysis because the country does not have any metropolitan areas according to the OECD definition (see Section 3.3). For results on innovative activity in small and medium-sized metropolitan areas (population=250,000 to 1.5 million) across selected OECD countries, see Table A6 in the Appendix.

Table 1: Shares of patents and population (in %) in large metropolitan areas (population >1.5 million) across selected OECD countries

Country	*Variable*	2000	2005	2010	2014	Change 2014/2000
Canada	Patents	45.63	40.22	36.42	42.55	0.93
	Population	31.36	32.15	32.72	33.27	1.06
	Patents/population ratio	1.46	1.25	1.11	1.28	0.88
Czech Republic	Patents	73.43	70.14	67.83	69.10	0.94
	Population	27.93	28.14	29.47	30.02	1.07
	Patents/population ratio	2.63	2.49	2.30	2.30	0.88
France	Patents	48.59	44.21	43.79	43.36	0.89
	Population	26.10	26.23	26.28	26.35	1.01
	Patents/population ratio	1.86	1.69	1.67	1.65	0.88
Germany	Patents	38.97	35.76	35.35	36.44	0.94
	Population	29.50	29.72	30.19	30.56	1.04
	Patents/population ratio	1.32	1.20	1.17	1.19	0.90
Hungary	Patents	31.48	41.32	36.33	29.74	0.94
	Population	22.35	22.60	23.66	24.21	1.08
	Patents/population ratio	1.41	1.83	1.54	1.23	0.87
Italy	Patents	29.85	28.83	26.10	23.79	0.80
	Population	22.56	22.48	22.45	23.06	1.02
	Patents/population ratio	1.32	1.28	1.16	1.03	0.78
Japan	Patents	69.86	71.24	74.43	73.40	1.05
	Population	44.63	45.36	46.32	46.92	1.05
	Patents/population ratio	1.57	1.57	1.61	1.56	1.00
Poland	Patents	30.51	25.71	25.65	26.43	0.87
	Population	15.78	15.75	15.76	15.91	1.01
	Patents/population ratio	1.93	1.63	1.63	1.66	0.86
South Korea	Patents	94.26	96.25	93.92	93.40	0.99
	Population	82.18	82.73	82.78	82.52	1.00
	Patents/population ratio	1.15	1.16	1.13	1.13	0.99
Spain	Patents	57.34	55.01	52.15	55.94	0.98
	Population	31.80	32.40	32.55	32.45	1.02
	Patents/population ratio	1.80	1.70	1.60	1.72	0.96
Sweden	Patents	32.65	27.89	34.88	34.79	1.07
	Population	20.35	20.78	21.62	22.43	1.10
	Patents/population ratio	1.60	1.34	1.61	1.55	0.97
United Kingdom	Patents	36.97	37.57	35.55	34.56	0.93
	Population	38.43	38.47	38.81	39.14	1.02
	Patents/population ratio	0.96	0.98	0.92	0.88	0.92
USA	Patents	80.11	80.13	81.11	83.10	1.04
	Population	62.02	62.33	62.51	62.86	1.01
	Patents/population ratio	1.29	1.29	1.30	1.32	1.02

Source: OECD database. Patents is the regional number of patent applications over the national total in %. Population is the regional number of people over the national total in %. The patents/population ratio is the quotient of these two shares.

approach is that the 'innovation requires large cities' argument suggests that there is a general trend across developed countries of innovation activities being concentrated in the largest cities. Comparable data on patenting is only available for the period 2000 to 2014.

The highest patent share of large metropolitan areas in 2014 is found in South Korea (93.4%), followed by the US (83.1%). In Germany, the patent share of large metropolitan areas is only about 36%. The value of 34.6% for the United Kingdom is surprisingly low given the dominant role of the London area in terms of population.[15] The lowest patent share of metropolitan areas (23.8%) is found in Italy. Among the European countries, only Spain and the Czech Republic have a majority of patents in large metropolitan areas. It is rather remarkable that in eight out of the 13 countries included in Table 1, the patent share of large metropolitan areas decreased by more than 5% from 2000 to 2014. In France and Italy, the patent share of large metropolitan areas dropped by about 10% between 2000 and 2014. In Poland the decrease was even higher (13%). Sweden is the only European country showing an increase of more than 5%, while the change of the patent share of other large metropolitan areas in the European countries included in our sample remained within the -5% to +5% range. Overall, the data show that there is no general tendency of an increasing concentration of innovative activity in large metropolitan areas in the early 21st century.

In order to understand whether the national share of innovative activity is higher than the national share of population in the largest metropolitan areas, we benchmark the concentration of innovative activities against the concentration of population. If large metropolitan areas have a patent/population ratio higher than 1, then this indicates an

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[15] The patent share of London in 2014 is about 27%. Other regions with high national shares of patents are Cambridgeshire (8.7%), Oxfordshire (4.5%) and Coventry (3.7%). None of these regions are regarded as large metropolitan areas based on the OECD definition. Furthermore, for Cambridgeshire the patent/population ratio achieves a remarkable value of 8.8, which means that the national patent share of the region is almost 9 times larger than its population share.

"urban premium" for innovative activity as suggested by the 'innovation requires large cities' argument. Large metropolitan areas might have a higher patent/population ratio because of the concentration of universities and other research facilities and the on average higher share of R&D employees in these regions.[16]

We do indeed find such an urban premium in all of the countries in our sample except in the United Kingdom (0.88 in 2014), where large metropolitan areas have lower patent/population ratios. The urban premium in the year 2014 is largest for the Czech Republic (2.3), Spain (1.74) and Poland (1.66). The values of the patent/population ratios for South Korea (1.13) and for the US (1.32), those countries with exceptional high shares of patents in large metropolitan areas, are in the mid-range. It is interesting to note that the urban premium is declining over time in most of the countries, with a 2% increase being revealed in the US.

In Table 2, we focus on innovative activities in the three largest metropolitan areas across the selected OECD countries in terms of population size. Countries with only one metropolitan area according to the OECD definition (Czech Republic, Hungary, Poland, and Sweden) are excluded. Since France and Spain have exactly three large metropolitan areas, the numbers for these two countries are the same as in Table 1. The focus on the three largest cities reveal some remarkable differences when compared to the analysis that includes all metropolitan areas. For the US, the patent share in the year 2014 drops to only 16% while the population share of these areas is 17%, suggesting that no urban premium exists for these largest agglomerations of the US. This clearly indicates that it is not the largest metropolitan areas in the US that have most of the patents. It is also remarkable that the patent share of the three largest metropolitan areas is decreasing over time.

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[16] Due to the higher share of R&D activities, a value of the patents/population ratio larger than 1 does not indicate higher productivity of R&D activities in large agglomerations. A measure for productivity of regional research could be the number of patents per inventor (see Section 4.4).

Table 2: Patents and population in the three largest metropolitan areas across selected OECD countries

Country	*Variable*	2000	2005	2010	2014	Change 2014/2000
Canada	Patents	42.69	38.07	33.37	39.02	0.91
	Population	28.15	28.80	29.11	29.42	1.05
	Patents/population ratio	1.52	1.32	1.15	1.33	0.87
France	Patents	48.59	44.21	43.79	43.35	0.89
	Population	26.10	26.23	26.28	26.35	1.01
	Patents/population ratio	1.86	1.69	1.67	1.65	0.88
Germany	Patents	10.10	10.62	10.63	11.49	1.14
	Population	16.27	16.25	16.38	16.37	1.01
	Patents/population ratio	0.62	0.65	0.65	0.70	1.13
Italy	Patents	23.15	20.46	19.77	17.36	0.75
	Population	18.74	18.69	18.66	19.28	1.03
	Patents/population ratio	1.24	1.09	1.06	0.90	0.73
Japan	Patents	61.69	61.87	63.66	63.20	1.02
	Population	33.27	33.89	34.74	35.22	1.06
	Patents/population ratio	1.85	1.83	1.83	1.79	0.97
South Korea	Patents	79.49	81.93	80.36	80.74	1.02
	Population	66.04	67.33	67.81	67.70	1.03
	Patents/population ratio	1.20	1.22	1.19	1.19	0.99
Spain	Patents	57.34	55.01	52.14	55.94	0.98
	Population	31.80	32.40	32.55	32.45	1.02
	Patents/population ratio	1.80	1.70	1.60	1.72	0.96
United Kingdom	Patents	32.03	33.17	30.92	30.20	0.94
	Population	30.55	30.65	31.08	31.48	1.03
	Patents/population ratio	1.05	1.08	1.00	0.96	0.92
USA	Patents	19.27	19.05	17.53	16.18	0.84
	Population	17.93	17.69	17.33	17.19	0.96
	Patents/population ratio	1.07	1.08	1.01	0.94	0.88

Source: OECD database. Only countries from Table 1 with at least three large metropolitan areas are considered. For the definition of variables see Table 1.

In Germany, the patent share of the three largest metropolitan areas is about 11% while the population share is slightly above 16%. The respective patent/population ratio (0.70 in 2014) is the lowest in the sample of countries, and is relatively stable over time. For the United Kingdom and Italy, the urban premium seen in the year 2000 disappears in 2014. While France has the highest patent/population ratio of 1.86 in the year 2000, there is a pronounced decrease to 1.65 by 2014. Even in a sparsely populated country like Canada, where metropolitan areas play a particularly important role, there is a significant decline of the urban premium from 1.52 to 1.32. Spain and Japan have the relatively most stable patent/population ratios and show the highest ratios of 1.72 and 1.79, respectively, in 2014.

Altogether, the rather pronounced heterogeneity across countries suggests that the largest metropolitan areas do not necessarily host a more than proportional share of innovative activity and that the largest agglomerations did not increase in importance over the 2000 to 2014 period. Rather, the urban premium for the three largest metropolitan areas is relatively stable or declining in all countries with the exception of Germany. These results suggest that the largest metropolitan areas of a country do not necessarily provide the most conducive framework conditions for, nor are specialized in innovation activity.

In order to investigate the concentration of patenting in those metropolitan areas that are most specialized in innovative activity, we focus on the three large metropolitan areas with the highest number of patents per population (Table 3). For Japan, France, and Spain the metropolitan areas are the same as in Table 1. The majority of all patents come from the three most innovative metropolitan areas in Japan (63%) and Spain (56%). A relatively high share can also be observed for France (43%). For South Korea the value is even 85%. The value for the US is, however, only about 23%; smaller than for the United Kingdom (31.5%) and only slightly larger than in Germany (19.5%).

However, the picture changes completely when benchmarking the patenting share against the population share of the three most innovative agglomerations per country. The highest ratio by far is found in the US (4.62), while the values are much lower (between 0.97 and 2.25) for the other countries. Thus, in 2014, the three US agglomerations with the highest number of patents per population contributed about 4.6 times more to the national patents (23.1%) than their share of the population is (5%). The US is also the only country of our sample that shows an

Table 3: Patents and population in the three most innovative large metropolitan areas across selected OECD countries

Country	*Variable*	2000	2005	2010	2014	Change 2014/2000
Canada	Patents	42.69	38.07	33.37	39.02	0.91
	Population	28.15	28.80	29.11	29.42	1.05
	Patents/population ratio	1.52	1.32	1.15	1.33	0.87
France	Patents	48.59	44.21	43.79	43.35	0.89
	Population	26.10	26.23	26.28	26.35	1.01
	Patents/population ratio	1.86	1.69	1.67	1.65	0.88
Germany	Patents	21.93	19.07	18.82	19.34	0.88
	Population	7.95	8.15	8.38	8.61	1.08
	Patents/population ratio	2.76	2.34	2.25	2.25	0.81
Italy	Patents	29.00	27.41	25.09	22.87	0.79
	Population	17.17	17.18	17.29	17.91	1.04
	Patents/population ratio	1.69	1.60	1.45	1.28	0.76
Japan	Patents	61.69	61.87	63.66	63.20	1.02
	Population	33.27	33.89	34.74	35.22	1.06
	Patents/population ratio	1.85	1.83	1.83	1.79	0.97
South Korea	Patents	84.07	86.34	83.93	85.18	1.01
	Population	55.13	56.78	57.67	57.82	1.05
	Patents/population ratio	1.52	1.52	1.46	1.47	0.97
Spain	Patents	57.34	55.01	52.14	55.94	0.98
	Population	31.80	32.40	32.55	32.45	1.02
	Patents/population ratio	1.80	1.70	1.60	1.72	0.96
United Kingdom	Patents	33.99	34.21	32.76	31.55	0.93
	Population	31.49	31.65	32.05	32.43	1.03
	Patents/population ratio	1.08	1.08	1.02	0.97	0.90
USA	Patents	17.58	17.68	20.46	23.11	1.31
	Population	5.05	4.95	4.95	5.00	0.99
	Patents/population ratio	3.48	3.57	4.14	4.62	1.33

Source: OECD database. Only countries from Table 1 with at least three large metropolitan areas are considered. For the definition of variables see Table 1.

increase of the patents/population ratio in the 2000 to 2014 period, while this figure is relatively stable or decreasing in all other countries of our sample.

Again, these results suggest that the size of an agglomeration is not a key factor in determining whether or not it is conducive to innovative activity. It is certain agglomerations rather than the largest ones that show an above average innovation performance. When considering the concentration of innovative activities in large metropolitan areas, the US is an extreme and exceptional case that is hardly in line with the general ‘innovation requires large cities’ argument in its purest sense.

4.2 Non-urban areas

To shed more light on the role of non-urban areas—functional regions with a population of less than 250 000—we calculate the national shares of patents registered in these areas (Table 4). These calculations identify two clear outliers, South Korea and the US, where the shares of patents in non-metropolitan areas are extremely low (0.6% in South Korea and 2.8% in the US). While the patent share of non-urban areas is also relatively low in Japan (between 4.3% and 5.5%) it is much higher in all other countries. The highest values are found for Switzerland (about 53%) and Italy (around 48%), two countries with a pronounced historically grown federal tradition. For most of the other countries the national share of patents registered in non-urban areas varies between around 10% and 40%. The development of the patent share of non-urban areas in the 2000 to 2014 period is rather stable in most of the countries in our sample. The patent share of non-urban areas increased by more than 5% in seven countries and decreased by more than 5% in six countries of our sample. Hence, the data show no general trend of a concentration of patenting in metropolitan areas.

In all countries the patents/population ratio for the non-urban areas is below 1, indicating that for most of these regions specializing in innovative activities is below the national average. Table 4 shows, however, some rather pronounced heterogeneity in this respect. While South Korea and the US have the lowest values of (0.28 and 0.26 in 2014, respectively), rather high values can be found for Switzerland (1.00) and Italy (0.93). The patents/population ratio decreased by more than 5% in four countries of the sample, remained relatively constant in three countries and increased by more than 5% in seven countries. Hence, there is also no general trend towards an increased specialization of innovative activities in non-urban areas.

Table 4: Patents and population in non-urban areas (less than 250,000 population) across selected OECD countries

Country	*Variable*	*2000*	*2005*	*2010*	*2014*	*Change 2014/2000*
Canada	Patents	28.24	26.58	25.84	26.38	0.93
	Population	51.79	50.63	49.91	49.04	0.95
	Patents/population ratio	0.55	0.53	0.52	0.54	0.99
Czech Republic	Patents	14.98	17.06	20.63	22.67	1.51
	Population	51.09	50.97	50.00	49.65	0.97
	Patents/population ratio	0.29	0.33	0.41	0.46	1.56
France	Patents	16.17	15.45	14.97	14.12	0.87
	Population	32.92	32.71	32.63	32.35	0.98
	Patents/population ratio	0.49	0.47	0.46	0.44	0.89
Germany	Patents	23.17	25.46	26.62	25.61	1.10
	Population	33.63	33.35	32.84	32.47	0.97
	Patents/population ratio	0.69	0.76	0.81	0.79	1.14
Hungary	Patents	33.33	28.57	33.20	41.69	1.25
	Population	44.52	44.47	43.78	43.40	0.97
	Patents/population ratio	0.75	0.64	0.76	0.96	1.28
Italy	Patents	42.43	44.69	47.74	47.97	1.13
	Population	52.47	52.40	52.33	51.75	0.99
	Patents/population ratio	0.81	0.85	0.91	0.93	1.15
Japan	Patents	5.06	4.98	4.32	5.53	1.09
	Population	7.11	6.99	6.85	6.76	0.95
	Patents/population ratio	0.71	0.71	0.63	0.82	1.15
Poland	Patents	21.19	27.59	25.43	25.23	1.19
	Population	50.64	50.59	50.60	50.33	0.99
	Patents/population ratio	0.42	0.55	0.50	0.50	1.20
South Korea	Patents	0.77	0.27	0.58	0.86	1.13
	Population	2.20	2.22	2.22	2.27	1.03
	Patents/population ratio	0.35	0.12	0.26	0.38	1.09
Spain	Patents	15.25	13.17	11.80	11.36	0.74
	Population	30.37	29.99	29.96	29.82	0.98
	Patents/population ratio	0.50	0.44	0.39	0.38	0.76
Sweden	Patents	29.03	27.92	26.73	27.34	0.94
	Population	46.87	46.09	44.85	44.04	0.94
	Patents/population ratio	0.62	0.61	0.60	0.62	1.00
Switzerland	Patents	51.20	50.40	51.52	52.91	1.03
	Population	53.24	53.09	52.89	52.89	0.99
	Patents/population ratio	0.96	0.95	0.97	1.00	1.04

Table 4 (continued)

Country	*Variable*	*2000*	*2005*	*2010*	*2014*	*Change 2014/2000*
United Kingdom	Patents	26.19	24.40	25.16	21.23	0.81
	Population	26.58	26.63	26.50	26.30	0.99
	Patents/population ratio	0.99	0.92	0.95	0.81	0.82
USA	Patents	3.10	3.25	2.79	2.57	0.83
	Population	10.24	10.06	9.98	9.84	0.96
	Patents/population ratio	0.30	0.32	0.28	0.26	0.86

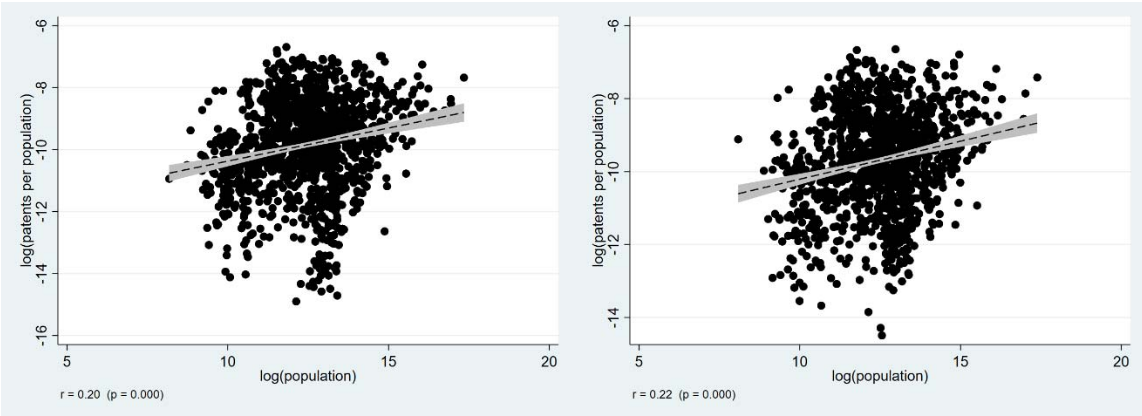
Source: OECD database. For the definition of variables see Table 1.

4.3 Regional size, and density, and innovation intensity

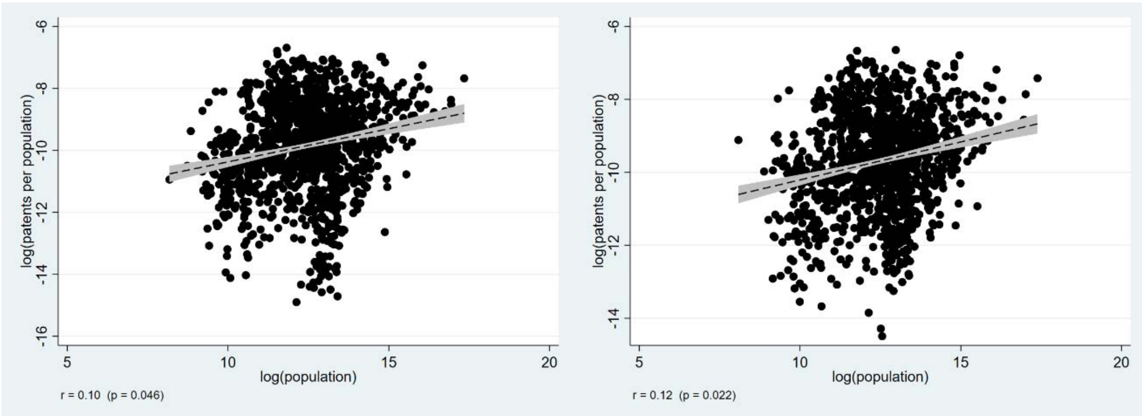
Our data also allows us to investigate the relationship between a region's population density and the number of patents per population (patent intensity). Most proponents of the 'innovation requires large cities' argument relate their hypotheses to size rather than density (e.g., Bettencourt, Lobo and Strumsky 2007: Bettencourt 2013; Gomez-Lievano, Patterson-Lomba and Hausmann 2016), while most arguments in the literature on agglomeration economies rely on density in terms of geographic proximity to a large number of actors (e.g., Storper and Venables 2004). We base our assessment on average values for two equally divided sub-periods 2000-2007 and 2008-2014.

Figure 1 clearly shows that there is no breathtaking linear relationship between population size and patents per population, nor between population size and patents per population across metropolitan areas. While there is a strong and statistically significant relationship when considering all regions (r=0.2, Figure 1a), there is a substantially weaker but still significant correlation for small and medium-sized metropolitan areas (r=0.1, Figure 1b). For large metropolitan regions there is no significant relationship between density and patents per population (Figure 1c). Overall, the results suggest that an increase in size, beyond the threshold of being a small and medium sized metropolitan area, has no

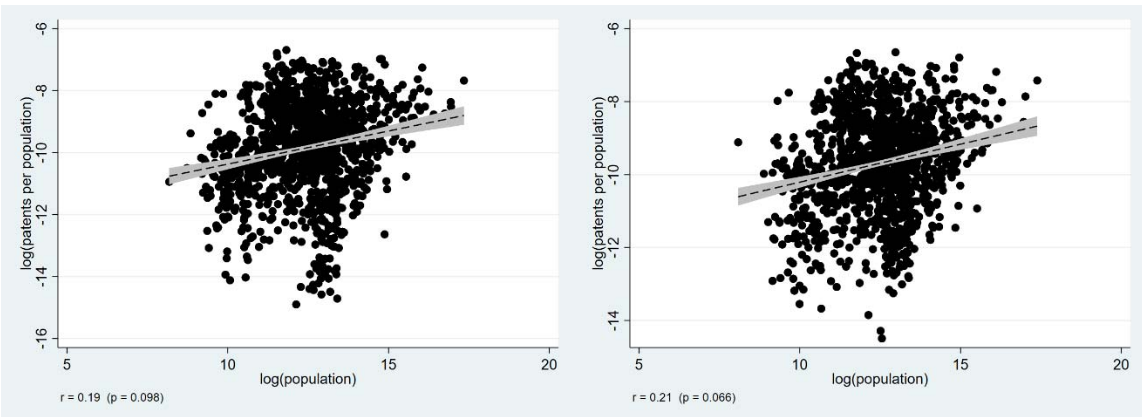
2000-2007 2008-2014



a) All regions



b) Small and medium-sized metropolitan regions

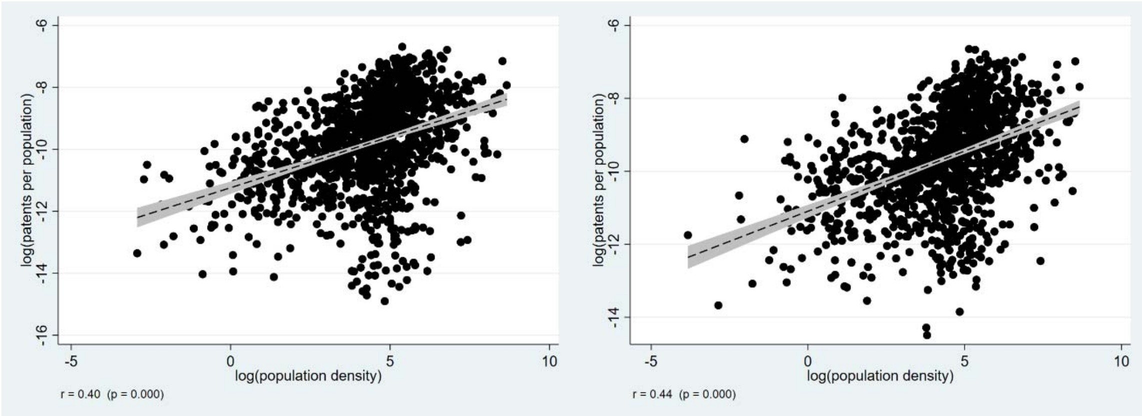


b) Large metropolitan regions

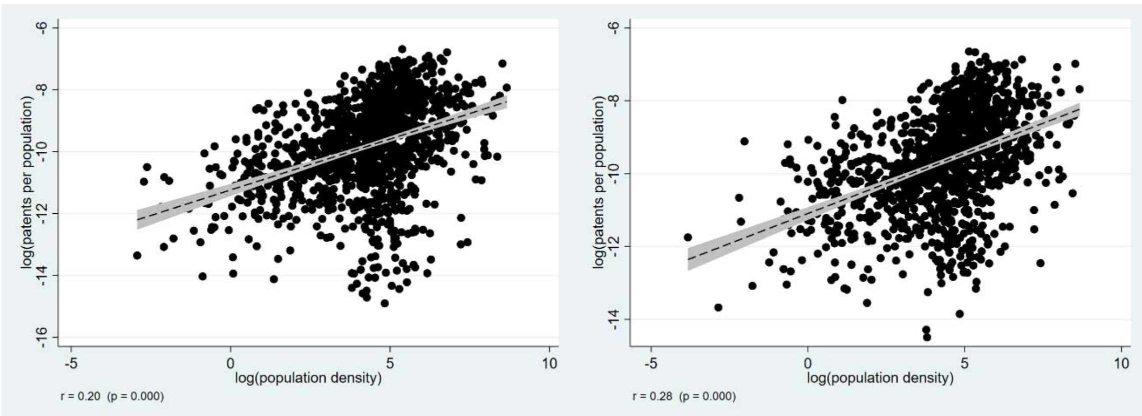
Figure 1: Population size and patents per population[17]

[17] The relationship between the number of inventors and patents per inventors is shown in Figures A5 in the Appendix.

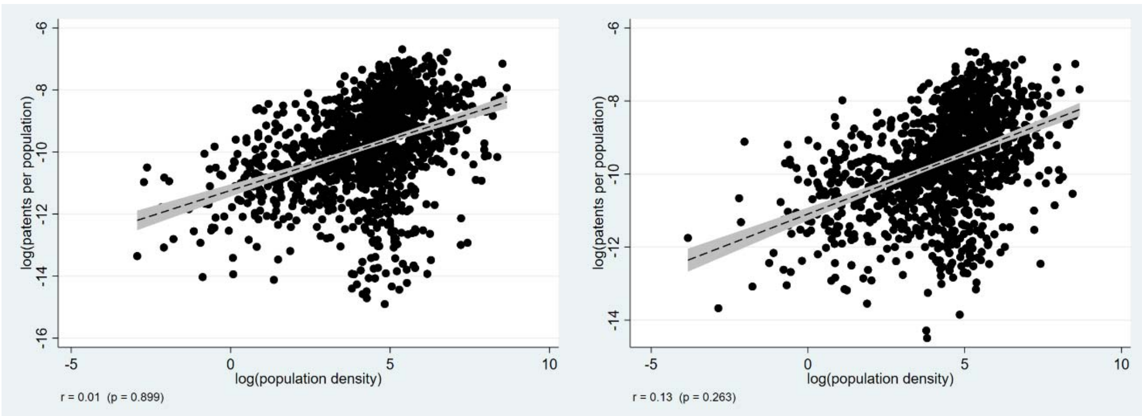
2000-2007 2008-2014



a) All regions



b) Small and medium-sized metropolitan regions



c) Large metropolitan regions

Figure 2: population density and patents per population[18]

[18] The relationship between density of inventors and patents per inventors is shown in Figures A6 in the Appendix.

additional impact on patenting activity. Figure 2 shows the relationship between population density and patents per population, confirming the patterns from Figure 1. The correlation coefficients indicate a slightly closer statistical relationship between density and small and medium-sized metropolitan regions.

To summarize, our results reveal large differences across our sample regarding the geographic concentration of inventive activity in large cities. The highest shares of patents in large metropolitan areas are found for South Korea and the US. These are also the countries (together with Japan) that have relatively low shares of patents in non-urban and rural regions. The result that the metropolitan areas in all countries have a higher number of patents per population (urban premium) than intermediate and non-urban regions does suggest some locational advantages of cities for innovative activities. However, the pronounced variation of the urban premium among the metropolitan areas of a country shows that the effect of size and density on innovative activity can considerably vary. In particular, it is not the largest agglomerations that have the highest urban premium.

In the majority of the countries in our sample, the concentration of patents and the urban premium found in large metropolitan areas have declined over the observation period. This indicates an increasing role of smaller cities and non-urban areas in innovative activity. Our results do reveal, however, an increasing trend in Hungary, Japan, Sweden and the US, all countries with rather uneven settlement structures.

4.4 Urban scaling in innovative activity across countries

We now analyze urban scaling following the approach of Bettencourt and Lobo (2016) who regress the number of patents on the size of the population of a region. In contrast to these authors who focus on metropolitan areas with a population greater than 500,000, we also consider all other regions in order to understand whether cities and metropolitan areas have a scaling advantage when compared to non-metropolitan areas. To this end, we regress the number of patents on the regional population. We make use of the average values for the periods 2000 to 2007, and 2008 to 2014. We interact population with country dummies where the US is the reference category. Significant interaction effects indicate whether urban scaling for innovative activity in the respective countries is more pronounced than in the US. We use the US as a benchmark because theories emphasizing the important role of large cities in innovative activity are mainly based on observations made for this country.

We first run the analysis for all regions of the countries in the sample (Models I and II in Table 5), i.e., we do not restrict the analysis to cities of a certain minimum size as was the case in some of the previous analyses (e.g., Bettencourt and Lobo 2016). In order to offer a comparison with the results of Bettencourt and Lobo (2016), we run the analysis for (metropolitan) regions with a population greater than 500,000 (see Table 5, Models III and IV).[19]

In the analysis for all regions (Models I and II in Table 5) we obtain a coefficient estimate for the US of about 1.45. We obtain significantly negative interaction effects in both time periods for Canada, Germany, Switzerland, and the UK. For Spain and Sweden there is a significantly negative interaction effect only in the first period. The negative effects are particularly pronounced for Canada and Switzerland. In Switzerland, the coefficient for urban scaling is only slightly above 1 while for Canada it is even below 1, indicating urban descaling. For the UK and Germany, the overall effect is only about 1.2.

Table A3 in the Appendix documents the scaling coefficient estimates and the respective confidence intervals. There are several countries for which the lower bound of the confidence interval is below one, indicating that the coefficient is not significantly different from one.

[19] This deviates from the OECD definition of metropolitan areas that we follow in other parts of the paper. The approach by Bettencourt and Lobo (2016) measures the role of urban scaling conditioned on a region being a metropolitan area. This is not suited to our primary interest, which is a comparison of innovative activity between metropolitan areas and rural regions.

Figures A1 in the Appendix show the respective country-specific scatterplots for the two time periods.

Table 5: Urban scaling based on regional population across selected OECD countries

	I	II	III	IV
	All regions		Metro regions > 500,000 population	
Dependent variable: Patents	2000-07	2008-14	2000-07	2008-14
Country dummies	Y	Y	Y	Y
Population	1.487***	1.445***	1.457***	1.481***
(reference: USA)	(0.048)	(0.049)	(0.101)	(0.103)
Population X France	0.006	0.099	-0.363	-0.417*
	(0.096)	(0.100)	(0.258)	(0.235)
Population X UK	-0.318***	-0.300***	-0.470***	-0.510***
	(0.066)	(0.067)	(0.170)	(0.163)
Population X Japan	0.116	0.247	-0.012	0.009
	(0.157)	(0.160)	(0.212)	(0.207)
Population X South Korea	0.014	-0.092	-0.281	-0.344
	(0.157)	(0.155)	(0.356)	(0.358)
Population X Germany	-0.291***	-0.276***	-0.415*	-0.401**
	(0.070)	(0.066)	(0.213)	(0.190)
Population X Spain	-0.277***	-0.057	0.252	0.092
	(0.099)	(0.083)	(0.201)	(0.193)
Population X Canada	-0.606***	-0.585***	-0.312**	-0.250
	(0.073)	(0.074)	(0.136)	(0.196)
Population X Italy	-0.182	-0.145	-0.620	-0.667
	(0.132)	(0.126)	(0.471)	(0.430)
Population X Switzerland	-0.419***	-0.389***	-0.555**	-0.665**
	(0.077)	(0.086)	(0.244)	(0.312)
Population X Sweden	0.118	0.192	-0.539*	-0.259
	(0.100)	(0.129)	(0.300)	(0.522)
Population X Poland	-0.218	0.204	-0.681	-0.739*
	(0.146)	(0.154)	(0.488)	(0.404)
Population X Czech Republic	0.173	0.080	0.000	0.000
	(0.144)	(0.170)	(0.000)	(0.000)
Population X Hungary	-0.260	-0.336*	0.217	0.050
	(0.238)	(0.201)	(0.419)	(0.522)
Number of observations	1,264	1,264	223	223
R^2	0.842	0.845	0.760	0.733

Notes: ***: statistically significant at the 1 percent level; **: statistically significant at the 5 percent level; * statistically significant at the 10 percent level. Robust standard errors in parentheses. Population and patents are log-transformed annual averages of their total number for the periods indicated in the column headings.

The results of the analysis for metropolitan regions with more than 500,000 population (Models III and IV in Table 5) resemble the patterns of the main analysis, although the levels of statistical significance tend to be

Table 6: Urban scaling based on number of regional inventors (inventor productivity) across regions of selected OECD countries

	I	II	III	IV
	All regions		Metro regions > 500,000 population	
Dependent variable: Patents	2000-07	2008-14	2000-07	2008-14
Country dummies	Y	Y	Y	Y
Inventors	0.974***	0.973***	0.988***	0.999***
(reference group: USA)	(0.005)	(0.006)	(0.007)	(0.009)
Inventors X France	-0.020*	-0.008	0.036	0.029
	(0.011)	(0.011)	(0.022)	(0.030)
Inventors X UK	-0.029***	-0.008	0.030	0.026
	(0.011)	(0.012)	(0.022)	(0.023)
Inventors X Japan	0.036***	0.074***	0.022	0.038***
	(0.011)	(0.011)	(0.016)	(0.014)
Inventors X South Korea	0.044	0.066***	0.013	0.056
	(0.028)	(0.025)	(0.046)	(0.034)
Inventors X Germany	0.009	0.004	0.032	0.022
	(0.010)	(0.011)	(0.021)	(0.024)
Inventors X Spain	-0.084***	-0.076***	-0.031	-0.027
	(0.019)	(0.022)	(0.051)	(0.053)
Inventors X Canada	-0.103***	-0.103***	0.001	0.008
	(0.012)	(0.013)	(0.027)	(0.023)
Inventors X Italy	0.023*	0.016	0.046	0.086*
	(0.013)	(0.016)	(0.042)	(0.048)
Inventors X Switzerland	-0.024	-0.026	0.083	0.037
	(0.018)	(0.022)	(0.087)	(0.092)
Inventors X Sweden	0.009	0.023	-0.089	0.260***
	(0.020)	(0.017)	(0.069)	(0.088)
Inventors X Poland	-0.177***	-0.077***	-0.024**	-0.082***
	(0.025)	(0.017)	(0.012)	(0.031)
Inventors X Czech Republic	-0.114***	-0.061	0.000	0.000
	(0.039)	(0.048)	(0.000)	(0.000)
Inventors X Hungary	-0.118**	-0.112	-0.023**	0.018
	(0.051)	(0.071)	(0.009)	(0.029)
Number of observations	1,264	1,264	223	223
R^2	0.993	0.992	0.994	0.992

Notes: ***: statistically significant at the 1 percent level; **: statistically significant at the 5 percent level; * statistically significant at the 10 percent level. Standard errors are robust. Robust standard errors in parentheses. Inventors and patents are annual averages for the periods indicated in the column headings.

weaker because of the smaller sample size. The scaling coefficients of 1.457 and 1.481 that we estimate for the US are higher than that of 1.291 estimated by Bettencourt, Lobo and Strumsky (2006) for the years 1980-2001.[20]

To explore whether inventors located in cities are more productive, we regress the number of patents on the number of inventors per region. If inventors living in metropolitan areas have more patents, the coefficient estimate and the lower bound of the confidence interval should exceed the value of one. Table 6 shows the results. We hardly find any urban mark-up on inventor productivity across countries (see also Table A5 and Figures A4 in the Appendix). Japan and South Korea are the only countries where inventors seem to be more productive in cities. While the scaling coefficient for the US is close to one, it is significantly below one in Canada, Spain, the UK, and in the former socialist countries of Eastern Europe. This indicates that inventors in metropolitan areas of these countries are less productive than those in other regions. When narrowing down the focus to the variation among metropolitan areas, Japan and Sweden stand out as the only countries where the productivity of inventive activity is significantly higher in agglomerations, but only for the period 2008 to 2014. For Poland we find a significantly negative scaling effect.

5. The general geographic concentration of patenting

In a final analysis we look at the overall geographic concentration of innovative activities. Our measure of geographic concentration is the well-known normalized Herfindahl-Hirsch Index (HHI) that assumes the value of 1 if innovative activity is completely concentrated in one region. In this final analysis we also consider the geographic concentration of R&D employment for which we have information at the level of OECD TLS2 large regions (e.g., NUTS1 regions for European countries; Federal States in the US) in the years 2008 and 2013.

[20] See Table A4 and Figures A3 in the Appendix for more details on country-specific coefficient estimates and scatterplots of urban scaling across metropolitan regions with more than 500,000 population.

Table 7: Geographic concentration of patenting activity (Herfindahl-Hirsch-Index) across selected OECD countries

Country	*Variable*	2000	2005	2010	2014	Change 2014/2000
Canada	Patents	0.060	0.061	0.066	0.058	0.97
	Population	0.023	0.024	0.024	0.025	1.06
	Patents/population ratio	2.567	2.557	2.735	2.337	0.91
Czech Republic	Patents	0.371	0.340	0.299	0.295	0.79
	Population	0.074	0.073	0.075	0.076	1.04
	Patents/population ratio	5.030	4.679	3.988	3.855	0.77
France	Patents	0.039	0.038	0.037	0.037	0.93
	Population	0.016	0.016	0.016	0.016	1.00
	Patents/population ratio	2.393	2.345	2.235	2.230	0.93
Germany	Patents	0.009	0.008	0.008	0.008	0.92
	Population	0.006	0.006	0.006	0.006	1.05
	Patents/population ratio	1.666	1.451	1.407	1.469	0.88
Hungary	Patents	0.138	0.133	0.122	0.099	0.72
	Population	0.084	0.084	0.084	0.085	1.01
	Patents/population ratio	1.642	1.587	1.450	1.165	0.71
Italy	Patents	0.044	0.040	0.035	0.033	0.75
	Population	0.020	0.019	0.019	0.020	1.03
	Patents/population ratio	2.236	2.054	1.780	1.630	0.73
Japan	Patents	0.136	0.141	0.161	0.190	1.40
	Population	0.039	0.040	0.041	0.042	1.07
	Patents/population ratio	3.450	3.495	3.889	4.497	1.30
Poland	Patents	0.070	0.048	0.055	0.053	0.76
	Population	0.016	0.016	0.016	0.016	1.00
	Patents/population ratio	4.388	2.997	3.449	3.326	0.76
South Korea	Patents	0.250	0.278	0.257	0.267	1.07
	Population	0.113	0.119	0.123	0.123	1.09
	Patents/population ratio	2.209	2.331	2.099	2.164	0.98
Spain	Patents	0.153	0.146	0.125	0.147	0.96
	Population	0.052	0.053	0.054	0.054	1.04
	Patents/population ratio	2.956	2.743	2.330	2.732	0.92
Sweden	Patents	0.170	0.164	0.188	0.188	1.10
	Population	0.101	0.103	0.107	0.110	1.09
	Patents/population ratio	1.685	1.587	1.758	1.709	1.01
Switzerland	Patents	0.102	0.098	0.094	0.096	0.94
	Population	0.078	0.079	0.080	0.080	1.02
	Patents/population ratio	1.301	1.246	1.184	1.199	0.92

Table 7 (continued)

Country	*Variable*	2000	2005	2010	2014	Change 2014/2000
United Kingdom	Patents	0.022	0.022	0.023	0.026	1.14
	Population	0.012	0.012	0.012	0.012	1.04
	Patents/population ratio	1.894	1.877	1.873	2.088	1.10
USA	Patents	0.047	0.044	0.046	0.050	1.06
	Population	0.022	0.021	0.021	0.021	0.98
	Patents/population ratio	2.200	2.049	2.195	2.394	1.09

Source: OECD database.

Table 7 shows the concentration patterns of patents. An international comparison is somewhat hampered by the fact that the value of the index is affected by the number of regions, which considerably varies across countries. However, we are more interested in the relating the concentration of patents to population density, which is comparable across countries. In all countries, the number of patents in the year 2014 is more geographically concentrated than population. The value of the ratio for Japan (4.5) is exceptionally high. The three countries with a pronounced federal tradition, Germany (1.47), Italy (1.63) and Switzerland (1.2) have rather low values.

The value of about 2.4 for the US is similar to the values for the United Kingdom (2.0) and France (2.2). Comparing the values of the index for different years clearly reveals that there is an increase in the concentration of patents relative to population by more than 5% in three countries, while the concentration decreases by more than 5% in eight countries. Hence, there is also no general trend of a geographic concentration of inventive activity.

Table 8: Geographic concentration (Herfindahl-Index) of R&D employment across selected OECD countries

Country	R&D employment		Population		R&D employment/ Population	
	2008	2013	2008	2013	2008	2013
Canada	0.314	0.295	0.237	0.236	1.322	1.249
Czech Republic	0.228	0.211	0.127	0.127	1.795	1.662
France	N/A	0.193	0.085	0.085	N/A	2.256
Germany	0.128	0.127	0.115	0.115	1.116	1.105
Hungary	0.341	0.340	0.170	0.173	2.006	1.962
Italy	0.102	0.103	0.082	0.082	1.251	1.252
Japan	N/A	N/A	0.149	0.152	N/A	N/A
Poland	0.130	0.129	0.078	0.079	1.654	1.639
South Korea	0.408	0.416	0.299	0.302	1.364	1.378
Spain	0.137	0.135	0.105	0.105	1.315	1.290
Sweden	0.202	0.198	0.155	0.158	1.299	1.255
Switzerland	N/A	N/A	0.165	0.165	N/A	N/A
United Kingdom	0.107	0.107	0.095	0.096	1.130	1.118
USA	0.051	0.051	0.044	0.044	1.159	1.155

Source: OECD database.

Analyzing the concentration patterns for R&D employment reveals additional insights (Table 8). First, the values for the ratio between the concentration of population and R&D employment are much lower than for patents. Thus, concentration is considerably more pronounced for innovation output as compared to innovation input. Second, France is the only ‘outlier’ with regard to the HHI ratio in the year 2013 (1.90 compared to values between 1.12 and 1.38 for the other countries). Germany and the US are also very similar with respect to the concentration of R&D employment. Third, there is high degree of stability in the values when comparing the years 2008 and 2013, years for which we have reliable data. Country differences in concentration patterns of innovative activity are particularly visible when it comes to patents but not as obvious in the case of R&D employment.

6. Discussion and Conclusions

6.1 Findings

Some prominent theories suggest that successful innovative activity benefits from agglomeration economies and thrives in large cities (Carlino and Kerr 2015; Glaeser and Hausman 2019; Florida, Adler and Mellander 2017). Our investigation of the geographic concentration of patents in a sample of developed countries reveals a great variety of environments where innovative activity is prevalent. We identified two countries where innovative activities are, indeed, concentrated in large metropolitan areas, South Korea and the US. This 'outlier' position held by the US and South Korea suggests that empirical results for these two extreme cases may be of rather limited relevance for other countries that are characterized by a more balanced geographic distribution of innovative activities. Interestingly, we find that even in the US it is not the largest agglomerations that have the highest shares of patents. We could not find any general trend towards an increasing concentration of innovative activities in large agglomerations over the 2000-2014 period (Section 4.1). In fact, our results show that there are more countries in our sample with a greater than 5% decrease in the share of patents registered in large metropolitan areas than countries where this share increased by more than 5%. These results clearly suggest that population density and agglomeration economies do not play a dominant role for regional innovative activity, at least in the great majority of countries. This clearly suggests that that innovation does not 'require' large cities.

The relationship between the number of patents and the size of regional population (urban scaling) shows more patents per population in most of the countries, with the highest scaling coefficient for the US. The obvious reason behind this result is that agglomerations tend to have higher levels of innovative activity caused by a higher share of inventors among that specific population. The scaling coefficient for the number of patents based on the number of inventors (patent productivity) is close to or below one for nearly all countries. This clearly indicates that inventors in larger agglomerations are not more productive in terms of having more patents.

Finally, we investigated the general regional concentration of population, patents, and R&D employment. In all countries, patents are considerably more geographically concentrated than population. This stronger concentration of patents is extremely high in Japan, while similar to the United Kingdom and France, the US holds a mid-range position in this respect. The difference between the concentration of patents and population is relatively small in the three countries of our sample that have a pronounced federal tradition: Germany, Italy and Switzerland. The geographic concentration of R&D employment is much less pronounced than the concentration of patents. The US is no 'outlier' with regard to the concentration of R&D employment compared to the concentration of population. There is an increase in the concentration of patents relative to population by more than 5% in three countries, while concentration is decreasing by more than 5% in eight countries. Hence, there is no general

Table 8: Country characteristics, patenting in non-urban areas, and urban scaling

Country	*Patent rate 2014*	*Share of patents in non-urban areas 2014*	*Urban scaling relative to the US*		*Population density*	*Geographic size*
			based on population	*based on inventors*		
USA	1.854	0.83	-	-	low	large
Canada	1.062	26.38	lower	lower	low	large
Czech Republic	0.312	22.67	n.s.	(lower)	moderate	small
France	1.804	12.12	n.s.	n.s.	moderate	medium
Germany	3.426	25.61	lower	n.s.	high	medium
Hungary	0.361	41.69	n.s.	(lower)	moderate	small
Italy	0.932	47.97	n.s.	n.s.	moderate	medium
Japan	3.526	5.53	n.s.	higher	high	medium
Poland	0.246	25.23	n.s.	lower	moderate	medium
South Korea	3.331	0.86	n.s.	(higher)	high	small
Spain	0.529	11.36	(lower)	lower	low	medium
Sweden	3.933	27.34	n.s.	n.s.	low	medium
Switzerland	4.929	52.91	lower	n.s.	moderate	small
United Kingdom	1.209	21.23	lower	(lower)	high	medium

Notes: The patent rate is the number of patents per 10,000 population (see Table A2 in the Appendix). Classifications in parentheses indicate that the difference to the US is statistically significant for only one of the two sub-periods.

trend towards higher geographic concentration of inventive activity. Comparing the geographic concentration of R&D employment in the years 2008 and 2013 shows only minor changes in all countries.

Quite remarkable, the extreme geographic concentration of patenting in South Korea and the US does not necessarily imply high levels of innovativeness in terms of the number of patents per population (patent rate). Comparing the geographic concentration of patenting in a country and the degree of urban scaling with its patent rate (Table 8) makes it clear that there are countries with lower degrees of concentration and urban scaling but higher levels of innovativeness (Germany, Sweden and Switzerland). There are also countries (the UK, for example) where the patent rate is similar to the US, but where the geographic concentration of patenting and urban scaling is less pronounced. Japan and South Korea are two countries where the concentration of patenting and the degree of urban scaling is comparable to the US. One reason for this could be because these two countries are much smaller in size and have a much higher population density. Altogether, Table 8 shows that countries deviating from the US pattern are not 'outliers'.

6.2 Limitations

The main limitation of our analysis is due to the characteristics of patents, our main indicator of innovative activity. However, as argued in Section 3.1, patents are the only measure for innovative activity that is comparable across countries. One might try to improve the comparability of patents by assessing their quality in terms of citations, or their economic value based on license income and patent renewal (Harhoff et al. 1999; Harhoff, Scherer and Vopel 2003). Such data could be used to determine if patents generated in large agglomerations are more valuable than those in less densely populated areas.

The most appropriate way of regionalizing patents is by assigning them to the residence of the inventor (for details see Maurat et al. 2008). This process creates another limitation because our analysis cannot be reasonably performed for very small spatial units such as inner cities or suburbs. Since the inventor's residence might be geographically distant from her/his workplace, a small-scale definition of the region such as the narrowly defined district or city would lead to considerably underestimating the respective city's level of inventive activity.[21]

6.3 Contribution to theory development

It goes without saying that a good theory is a radical simplification of reality and focuses on the most relevant factors and relationships. We also recognize the role of agglomeration economies in promoting successful innovative activities. However, our results clearly indicate that the role of agglomeration economies is much less pronounced than many authors suggest (e.g., Bettencourt 2013; Carlino and Kerr 2015; Florida, Adler and Mellander 2017), and that other factors are considerably more important for the great majority of the countries in our sample. Hence, the popular theory that builds almost entirely on the role of agglomeration economies is much too simple to explain the regional distribution of innovative activities, and is largely inappropriate for many countries.[22]

A case study of the geographic distribution of innovative activity in Germany by Fritsch and Wyrwich (2020) suggests a number of other factors that may explain the regional distribution of inventive and innovative activity. These factors are the regional settlement structure, the geographic distribution of knowledge sources, the local availability of finance, the educational system, and the level of political decentralization. The characteristics of the political system, settlement structure, and geographic distribution of knowledge sources are, of course, related in the sense that a federal political system may be conducive to the emergence of a rather decentralized settlement structure, as well as geographically

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[21] Assigning a patent to the location of the filing organization would lead to a misspecification since many firms and organizations file their patents at the location of their headquarters even if the respective research was entirely conducted in a distant branch facility.

[22] Our result show that even in the US it is not the largest agglomerations that have the highest shares of patents. This clearly indicates that any theory that prioritizes the role of agglomeration economies has limited relevance, even in outlier cases.

scattered institutions of research and higher education. Since the political system and the settlement structure have pronounced historical roots and develop over long periods of time, the historical roots, regional traditions and cultures may play important roles (Fritsch, Obschonka and Wyrwich 2019).

6.4 Policy implications

The main policy implication of our research is that innovation does not require large cities, but can also be successfully conducted in non-urban environments.[23] Hence, concentrating public R&D spending in large agglomerations (see, for example, Glaeser and Hausman 2019) is not necessarily the best strategy recommendation. Instead, policy programs such as the EU Smart Specialization Strategy (Foray 2014; McCann 2015; McCann and Ortega Argilés 2015) that aim at stimulating regional development of low-density and lagging regions by initiating and supporting innovation processes may be quite successful. If agglomeration economies are of only limited relevance for successful innovative activities, then such programs are not necessarily an inefficient or wasteful allocation of resources as some scholars suggest (e.g., Glaeser and Hausman 2019).

Since our research shows that agglomeration economies are not the main factor determining the spatial structure of innovative activities in most countries, the policy recommendations promoted by popular theories to concentrate public spending on large agglomerations may be misleading and harmful. Therefore, policymakers are strongly advised to consider influences other than city size or population density.

6.5 Avenues for further research

An important avenue of further research could be to overcome the limitations of our analysis due to the weaknesses of patents as an indicator for innovative activity (Section 3.1). One step could be to develop

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[23] For a detailed exposition of the German case where many highly innovative firms are located in rural areas, see Fritsch and Wyrwich (2020).

and apply measures for the quality of a patent and compare this quality across regions. In general, an important step forward would be the development of more fine-tuned indicators for innovative activity that are comparable across countries and regions.[24]

A key question that follows from our analyses concerns the factors that determine the location of innovative activities and the region-specific determinants of their success. Why is innovative activity concentrated in certain regions? To what extent are actors attracted to certain regions to engage in innovative activities? Why do certain non-urban areas engender successful innovative activities? An in-depth study of the geographic distribution of innovative activities in Germany (Fritsch and Wyrwich 2020) identifies the important role played by the political/administrative structures and traditions that obviously affected settlement structures, as well as the location of knowledge sources (i.e., universities) and the financial system on innovative activity. In particular, the German case study demonstrates the long-lasting effect of historical factors for current structures. The educational system, labor market regulation and the tax treatment of inheriting a business also seem to have an effect in the German context. The interplay of these dynamics may be suitable candidates as factors for a closer inspection of causal relationships in case studies for other countries.

An important element of such investigations for other countries could be analyses of the innovation behavior of firms that are located outside of large agglomerations. Why are some firms located in remote rural areas innovative and economically successful? How do these firms acquire the qualified labor that they need for their innovative activities? Do these firms have to adapt their innovation behavior based on the locational conditions? Is a decentralized settlement structure with a variety of easily

[24] The data of the Community Innovation Survey (CIS) are not suited for an analysis across regions because innovative activities of subsidiary locations of a firm are all assigned to the firm's headquarter and not to the region where the R&D took place. See https://ec.europa.eu/eurostat/web/microdata/community-innovation-survey

accessible smaller and medium-sized cities (as it is found in many parts of Europe) important for innovative activities in rural areas?

Metropolitan areas and rural regions may have differing sources of inspiration that drive innovation. Based on this presumption, firms in rural and peripheral regions may focus on different types of innovations, or have different modes of innovative activity than firms in large urban areas. It has been argued that actors in rural areas engage in incremental innovations, while radical innovation primarily takes place in cities (Duranton and Puga 2011; Shearmur 2011). For example, there is evidence that digital technologies are spurring an increase in the concentration of innovative activities in selected cities (Paunov et al. 2019). There also seems to be a tendency for start-up activity in new high-tech sectors becoming more concentrated in cities (Florida and King 2018; Fritsch and Wyrwich 2020).

Another appropriate avenue for future research is to investigate and explain the role of public policy in this respect. How can public policy effect the geographic distribution of innovative activities? To what extent does policy aimed at rural and lagging areas stimulate innovative activities? Can an appropriate time period be established in which to expect significant changes of regional innovative activities? Do differing national and local policies of OECD countries explain the existing differences in the role that metropolitan areas play in innovative activity?

Any of these analyses could focus on, or distinguish between different types of innovation, such as radical vs. incremental, high vs. low tech, science-based vs. engineering or artistic-based. Such types of empirical analyses should help to provide a more relevant basis for policy decisions than the simple “big is efficient” paradigm.

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Appendix

Tables

Table A1: Number of regions by spatial category in selected OECD countries

Country	Large mettropolitan areas (>1.5 million population)	Metropolitan areas (250,000 to 1.5 million population)	Share of TL3 regions in large metropolitan regions	Share of TL3 regions in metropolitan regions	Share of TL3 regions in non-metropolitan regions
Canada	4	12	0.041	0.024	0.935
Czech Republic	1	4	0.143	0.286	0.571
France	3	30	0.115	0.313	0.573
Germany	8	60	0.154	0.358	0.488
Hungary	1	4	0.100	0.200	0.700
Italy	4	18	0.055	0.164	0.782
Japan	5	33	0.170	0.702	0.128
Poland	2	17	0.111	0.292	0.597
South Korea	6	5	0.563	0.375	0.063
Spain	3	16	0.060	0.320	0.620
Sweden	1	3	0.048	0.143	0.810
Switzerland	0	5	0.000	0.192	0.808
United Kingdom	5	34	0.216	0.410	0.374
USA	33	69	0.185	0.404	0.410

Table A2: Number of patents per 10,000 population across selected OECD countries

Country	*2000*	*2005*	*2010*	*2014*
Canada	1.023	1.327	1.240	1.062
Czech Republic	0.207	0.214	0.286	0.312
France	1.442	1.660	1.686	1.804
Germany	3.098	3.488	3.613	3.426
Hungary	0.105	0.164	0.252	0.361
Italy	0.801	1.009	0.929	0.932
Japan	2.005	2.640	3.065	3.526
Poland	0.044	0.054	0.126	0.246
South Korea	0.555	1.770	2.453	3.331
Spain	0.267	0.444	0.563	0.529
Sweden	3.906	3.557	3.846	3.933
Switzerland	4.365	5.120	5.159	4.929
United Kingdom	1.341	1.262	1.164	1.209
USA	1.811	2.011	1.659	1.854

Source: OECD database.

Table A3: Summary of urban scaling based on regional population across all regions

	Coefficient	Standard error	Limits of five percent confidence interval lower	upper	N	R2	Difference to the US
Year 2000							
All countries	0.970***	0.020	0.931	1.010	1264	0.583	
USA	1.487***	0.048	1.393	1.582	175	0.818	
France	1.493***	0.083	1.327	1.659	88	0.791	n.s.
UK	1.170***	0.045	1.081	1.259	91	0.769	***
Japan	1.604***	0.151	1.299	1.909	44	0.641	n.s.
South Korea	1.502***	0.162	1.141	1.863	12	0.777	n.s.
Germany	1.196***	0.051	1.096	1.296	264	0.61	***
Spain	1.211***	0.087	1.035	1.386	50	0.717	***
Canada	0.882***	0.055	0.773	0.990	291	0.711	***
Italy	1.306***	0.122	1.063	1.548	108	0.469	n.s.
Switzerland	1.069***	0.061	0.942	1.195	26	0.885	***
Sweden	1.605***	0.091	1.414	1.796	21	0.922	n.s.
Poland	1.270***	0.139	0.991	1.548	62	0.686	n.s.
Czech Republic	1.660***	0.142	1.361	1.960	19	0.839	n.s.
Hungary	1.227***	0.250	0.676	1.778	13	0.616	n.s.
Year 2014							
All countries	0.985***	0.019	0.947	1.023	1264	0.627	
USA	1.445***	0.048	1.349	1.540	175	0.808	
France	1.543***	0.087	1.370	1.717	88	0.797	n.s.
UK	1.145***	0.046	1.053	1.237	91	0.764	***
Japan	1.692***	0.154	1.380	2.004	44	0.664	n.s.
South Korea	1.352***	0.160	0.997	1.708	12	0.766	n.s.
Germany	1.168***	0.044	1.082	1.255	264	0.655	***
Spain	1.388***	0.068	1.250	1.525	50	0.801	n.s.
Canada	0.860***	0.055	0.752	0.968	291	0.714	***
Italy	1.299***	0.116	1.070	1.529	108	0.472	n.s.
Switzerland	1.056***	0.073	0.904	1.207	26	0.874	***
Sweden	1.637***	0.124	1.376	1.897	21	0.91	n.s.
Poland	1.649***	0.147	1.354	1.944	62	0.722	n.s.
Czech Republic	1.524***	0.170	1.165	1.883	19	0.772	n.s.
Hungary	1.108***	0.210	0.646	1.570	13	0.661	*

Notes: ***: statistically significant at the 1 percent level; * statistically significant at the 10 percent level. Standard errors are robust.

Table A4: Summary of urban scaling based on regional population across metropolitan regions (population > 500,000 population)

	Coefficient	Standard error	Limits of five percent confidence interval lower	upper	N	R2	Difference to the US
Year 2000							
All countries	1.125***	0.069	0.989	1.260	223	0.464	
USA	1.457***	0.096	1.266	1.648	74	0.698	
France	1.094***	0.241	0.570	1.619	14	0.572	n.s.
UK	0.988***	0.135	0.703	1.272	20	0.779	***
Japan	1.445***	0.181	1.075	1.816	30	0.642	n.s.
South Korea	1.176**	0.370	0.270	2.082	8	0.646	n.s.
Germany	1.042***	0.183	0.664	1.420	26	0.534	*
Spain	1.709***	0.185	1.272	2.146	9	0.91	n.s.
Canada	1.145***	0.095	0.931	1.360	11	0.826	**
Italy	0.837	0.469	-0.195	1.869	13	0.201	n.s.
Switzerland	0.902	0.362	-3.696	5.499	3	0.756	**
Sweden	0.918	0.459	-4.909	6.746	3	0.667	*
Poland	0.776	0.517	-0.488	2.040	8	0.405	n.s.
Czech Republic	-	-	-	-	-	-	-
Hungary	1.674	0.661	-6.720	10.068	3	0.762	n.s.
Year 2014							
All countries	1.142***	0.068	1.007	1.276	223	0.515	
USA	1.481***	0.098	1.285	1.677	74	0.69	
France	1.064***	0.213	0.599	1.529	14	0.565	*
UK	0.971***	0.124	0.710	1.232	20	0.759	***
Japan	1.491***	0.174	1.134	1.848	30	0.658	n.s.
South Korea	1.137**	0.371	0.229	2.046	8	0.623	n.s.
Germany	1.080***	0.155	0.760	1.400	26	0.633	**
Spain	1.574***	0.173	1.164	1.984	9	0.887	n.s.
Canada	1.231***	0.173	0.841	1.621	11	0.789	n.s.
Italy	0.815*	0.426	-0.123	1.752	13	0.189	n.s.
Switzerland	0.817	0.478	-5.252	6.885	3	0.594	**
Sweden	1.222	0.830	-9.329	11.773	3	0.52	n.s.
Poland	0.742	0.422	-0.291	1.775	8	0.415	*
Czech Republic	-	-	-	-	-	-	-
Hungary	1.532	0.830	-9.020	12.083	3	0.63	n.s.

Notes: ***: statistically significant at the 1 percent level; **: statistically significant at the 5 percent level; * statistically significant at the 10 percent level. Standard errors are robust.

Table A5: Summary of urban scaling based on the number of regional inventors (inventor productivity) across all regions

	Coefficient	Standard error	Limits of five percent confidence interval lower	upper	N	R2	Difference to the US
Year 2000							
All countries	0.942***	0.002	0.937	0.947	1,264	0.989	
USA	0.974***	0.005	0.964	0.985	175	0.996	Ref
France	0.954***	0.010	0.935	0.974	88	0.989	*
UK	0.945***	0.009	0.927	0.963	91	0.992	***
Japan	1.010***	0.010	0.991	1.030	44	0.994	***
South Korea	1.018***	0.030	0.952	1.085	12	0.991	n.s.
Germany	0.983***	0.008	0.967	0.999	264	0.983	n.s.
Spain	0.890***	0.018	0.853	0.927	50	0.979	***
Canada	0.872***	0.011	0.850	0.894	291	0.984	***
Italy	0.997***	0.012	0.974	1.020	108	0.984	*
Switzerland	0.950***	0.017	0.914	0.986	26	0.987	n.s.
Sweden	0.983***	0.020	0.941	1.026	21	0.993	n.s.
Poland	0.798***	0.025	0.748	0.847	62	0.935	***
Czech Republic	0.860***	0.041	0.775	0.946	19	0.981	***
Hungary	0.856***	0.054	0.736	0.975	13	0.971	**
Year 2014							
All countries	0.947***	0.003	0.941	0.953	1,264	0.988	
USA	0.973***	0.006	0.961	0.985	175	0.995	Ref
France	0.965***	0.010	0.946	0.984	88	0.993	n.s.
UK	0.964***	0.011	0.943	0.986	91	0.989	n.s.
Japan	1.047***	0.009	1.029	1.065	44	0.992	***
South Korea	1.039***	0.026	0.982	1.097	12	0.996	***
Germany	0.977***	0.009	0.958	0.995	264	0.982	n.s.
Spain	0.897***	0.021	0.855	0.939	50	0.983	***
Canada	0.870***	0.012	0.847	0.893	291	0.983	***
Italy	0.989***	0.014	0.961	1.017	108	0.977	n.s.
Switzerland	0.946***	0.021	0.903	0.990	26	0.987	n.s.
Sweden	0.996***	0.017	0.961	1.031	21	0.995	n.s.
Poland	0.896***	0.016	0.864	0.927	62	0.962	***
Czech Republic	0.911***	0.050	0.806	1.017	19	0.969	n.s.
Hungary	0.861***	0.076	0.693	1.028	13	0.964	n.s.

Notes: ***: statistically significant at the 1 percent level. **: statistically significant at the 5 percent level; *: statistically significant at the 10 percent level. Standard errors are robust.

Table A6: Summary of urban scaling based on the number of regional inventors (inventor productivity) across metropolitan regions (population > 500,000 population)

	Coefficient	Standard error	Limits of five percent confidence interval lower	upper	N	R2	Difference to the US
Year 2000							
All countries	1.004***	0.006	0.992	1.016	223	0.989	
USA	0.988***	0.006	0.975	1.000	74	0.996	
France	1.024***	0.021	0.977	1.070	14	0.988	n.s.
UK	1.017***	0.021	0.974	1.061	20	0.991	n.s.
Japan	1.010***	0.014	0.981	1.039	30	0.994	n.s.
South Korea	1.000***	0.049	0.879	1.122	8	0.983	n.s.
Germany	1.020***	0.020	0.979	1.061	26	0.992	n.s.
Spain	0.957***	0.053	0.831	1.084	9	0.984	n.s.
Canada	0.989***	0.027	0.927	1.051	11	0.988	n.s.
Italy	1.034***	0.042	0.941	1.127	13	0.977	n.s.
Switzerland	1.071*	0.140	-0.714	2.856	3	0.967	n.s.
Sweden	0.899*	0.112	-0.521	2.319	3	0.97	n.s.
Poland	0.964***	0.010	0.939	0.989	8	0.993	**
Czech Republic	-	-	-	-	-	-	-
Hungary	0.965***	0.010	0.842	1.088	3	1	**
Year 2014							
All countries	1.017***	0.007	1.002	1.031	223	0.987	
USA	0.999***	0.009	0.981	1.016	74	0.995	
France	1.028***	0.029	0.965	1.091	14	0.976	n.s.
UK	1.025***	0.021	0.981	1.069	20	0.989	n.s.
Japan	1.037***	0.010	1.016	1.059	30	0.99	***
South Korea	1.055***	0.036	0.967	1.143	8	0.993	n.s.
Germany	1.020***	0.022	0.976	1.065	26	0.989	n.s.
Spain	0.972***	0.055	0.842	1.102	9	0.972	n.s.
Canada	1.007***	0.022	0.956	1.057	11	0.992	n.s.
Italy	1.085***	0.048	0.980	1.190	13	0.978	*
Switzerland	1.035*	0.149	-0.854	2.925	3	0.96	n.s.
Sweden	1.259*	0.142	-0.542	3.060	3	0.975	***
Poland	0.917***	0.032	0.838	0.996	8	0.988	***
Czech Republic	-	-	-	-	-	-	-
Hungary	1.017**	0.044	0.454	1.580	3	0.996	n.s.

Notes: ***: statistically significant at the 1 percent level. **: statistically significant at the 5 percent level; *: statistically significant at the 10 percent level. Standard errors are robust.

Table A7: Innovation activity in small and medium-sized metropolitan areas (250 000 to 1.5 million population) across selected OECD countries

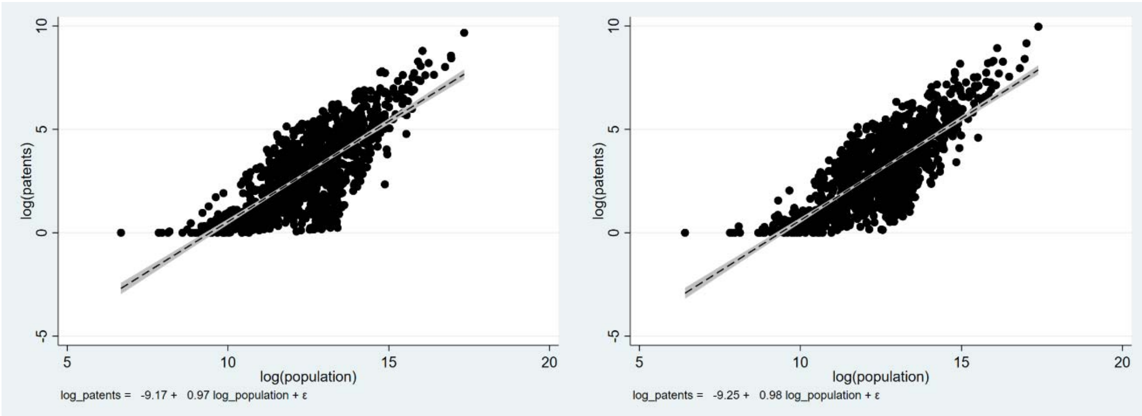
Country	*Variable*	2000	2005	2010	2015	Direction of change
Canada	Patents	26.13	33.20	37.74	31.41	+
	Population	18.57	18.75	18.42	18.69	=
	Patents/population-ratio	1.41	1.77	2.05	1.68	+
Czech Republic	Patents	11.59	12.80	11.54	14.29	+
	Population	21.45	21.36	20.52	20.23	-
	Patents/population-ratio	0.54	0.60	0.56	0.71	+
France	Patents	35.25	40.34	41.23	44.00	+
	Population	40.98	41.06	41.10	41.49	=
	Patents/population-ratio	0.86	0.98	1.00	1.06	+
Germany	Patents	37.86	38.77	38.02	38.53	=
	Population	36.87	36.95	36.97	37.00	=
	Patents/population-ratio	1.03	1.05	1.03	1.04	=
Hungary	Patents	35.19	30.36	30.47	26.84	-
	Population	33.13	32.93	33.54	32.31	=
	Patents/population-ratio	1.06	0.92	0.91	0.83	-
Italy	Patents	27.73	26.48	26.16	30.00	+
	Population	25.13	25.12	25.30	25.64	=
	Patents/population-ratio	1.10	1.05	1.03	1.17	+
Japan	Patents	25.08	23.78	21.25	21.41	-
	Population	48.26	47.65	46.83	46.15	=
	Patents/population-ratio	0.52	0.50	0.45	0.46	-
Poland	Patents	48.31	46.55	48.92	49.57	=
	Population	38.41	38.19	34.75	33.97	-
	Patents/population-ratio	1.26	1.22	1.41	1.46	+
South Korea	Patents	5.02	3.48	5.50	4.89	=
	Population	15.62	15.04	15.00	15.04	=
	Patents/population-ratio	0.32	0.23	0.37	0.33	=
Spain	Patents	24.95	28.95	32.32	29.67	+
	Population	38.79	38.44	38.45	38.66	=
	Patents/population-ratio	0.64	0.75	0.84	0.77	+
Sweden	Patents	38.33	44.19	38.39	38.22	=
	Population	32.78	33.34	33.54	33.55	=
	Patents/population-ratio	1.17	1.33	1.14	1.14	=
Switzerland	Patents	48.80	49.60	48.48	50.54	=
	Population	46.76	46.91	47.11	47.16	=
	Patents/population-ratio	1.04	1.06	1.03	1.07	=
United Kingdom	Patents	36.30	37.44	38.60	45.33	+
	Population	33.81	33.69	33.50	33.37	=
	Patents/population-ratio	1.07	1.11	1.15	1.36	+
USA	Patents	16.98	16.85	16.31	14.96	-
	Population	28.10	27.97	27.85	27.62	=
	Patents/population-ratio	0.60	0.60	0.59	0.54	-

Source: OECD database. Direction of change for 2000-2015 period: +: growth by at least 5%; -: decrease by at least 5%; =: changes less than 5%.

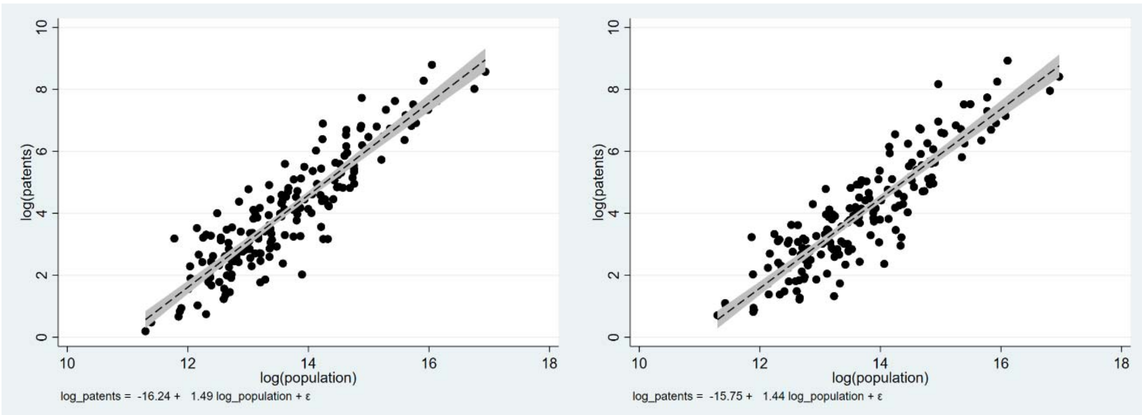
Scatterplots

Figures A1: Urban scaling

2000-2007 2008-2014



All 14 countries



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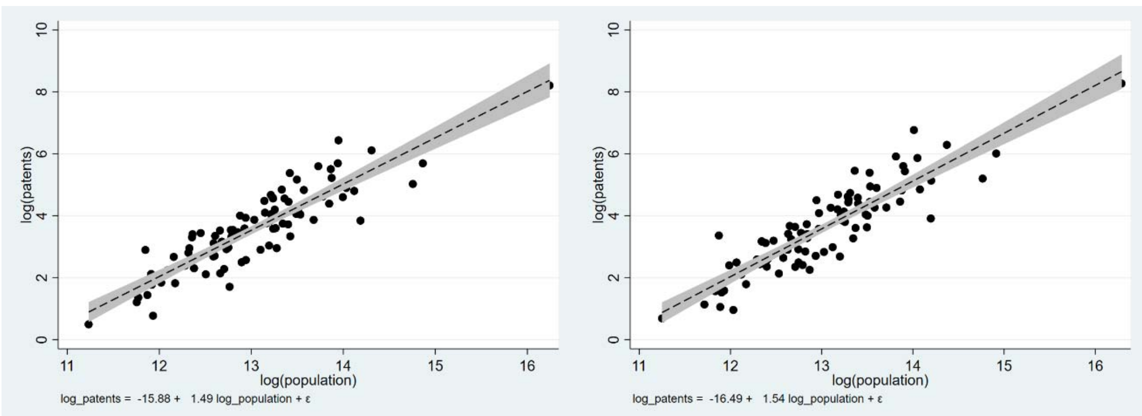
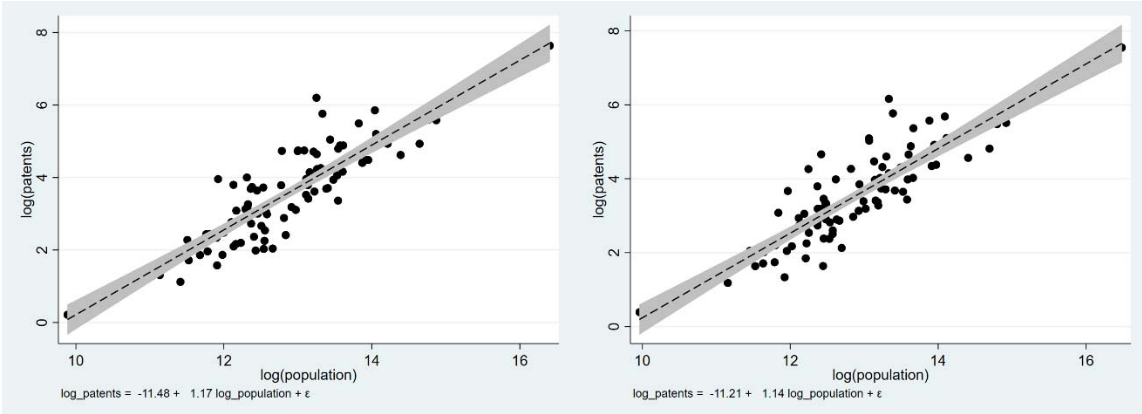


France

2000-2007 | 2008-2014



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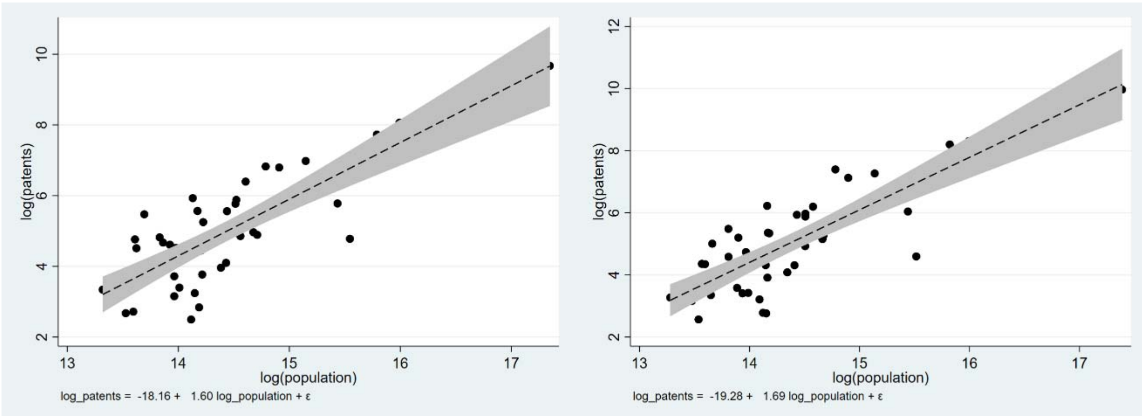
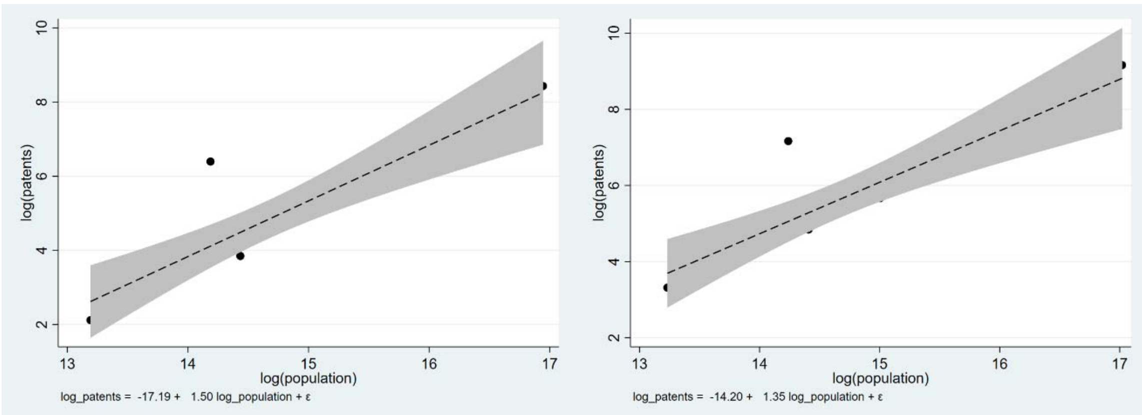
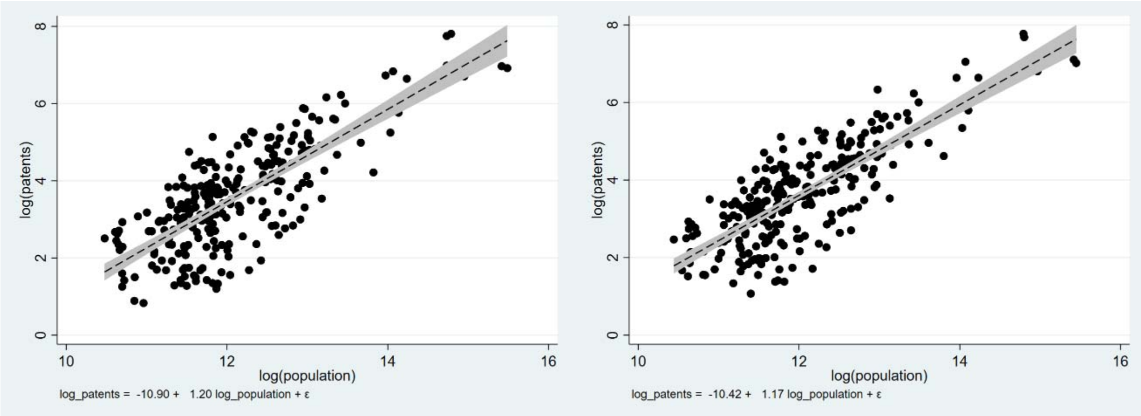


Japan



South Korea

2000-2007 2008-2014



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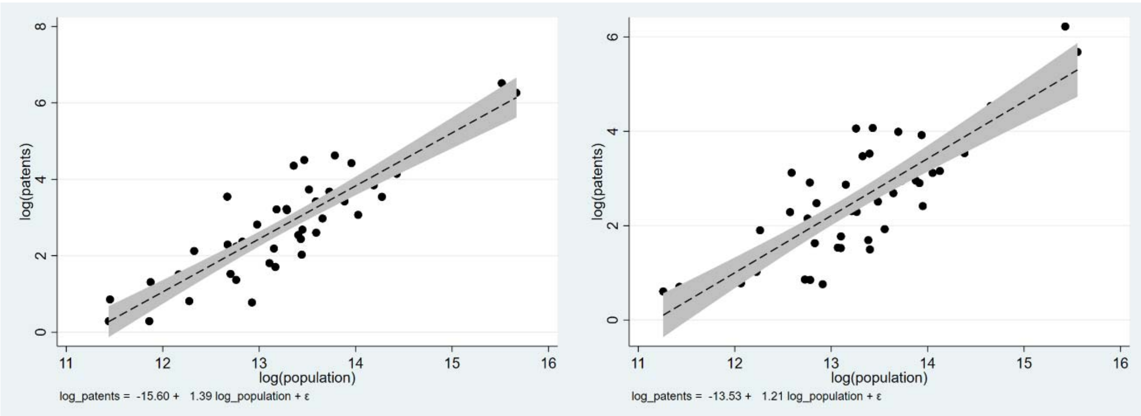

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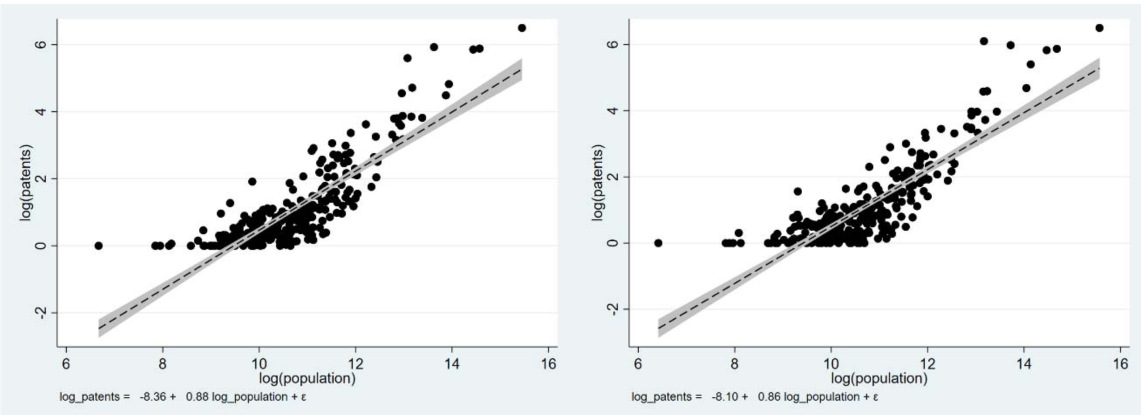
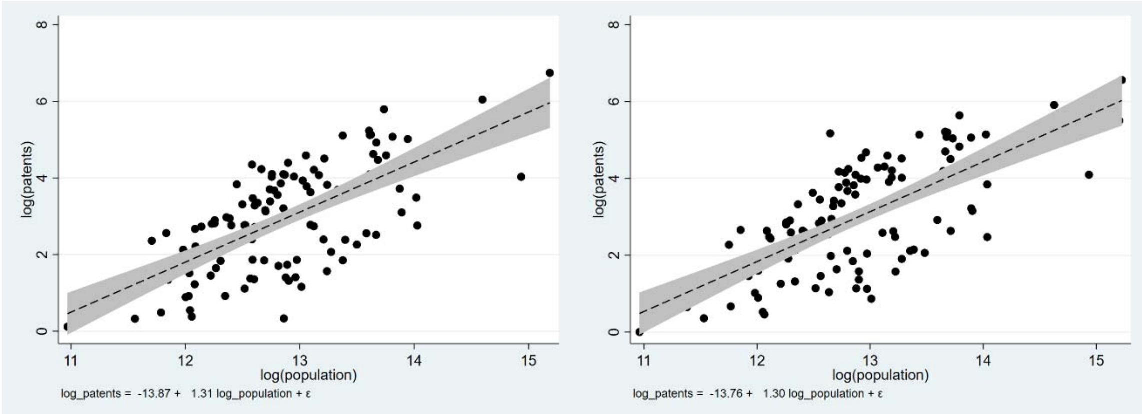
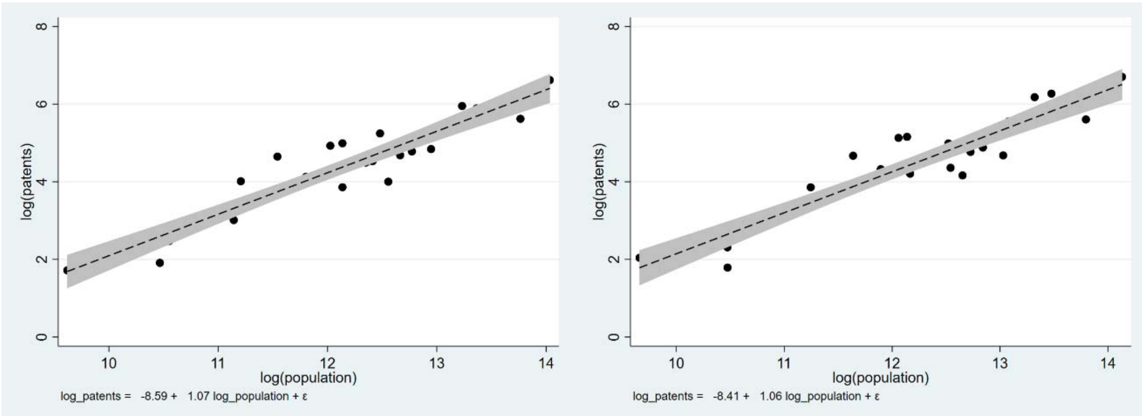


Canada

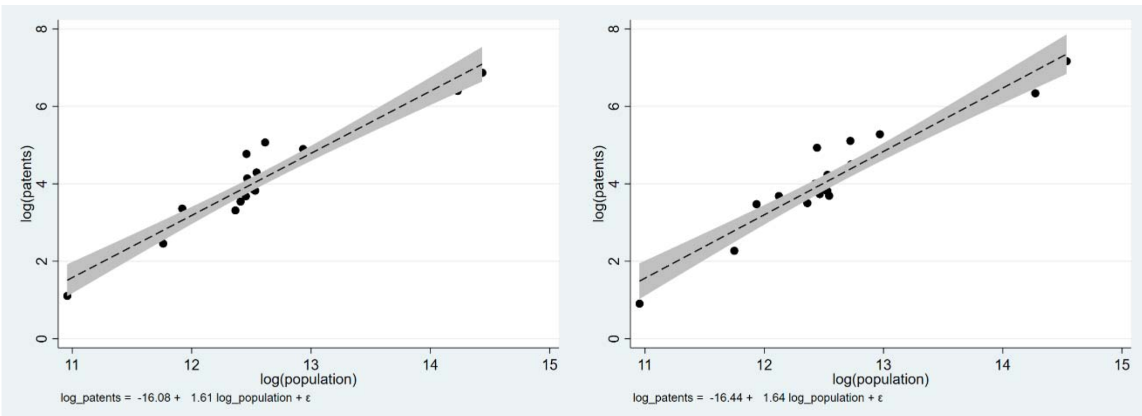
2000-2007 2008-2014



Italy

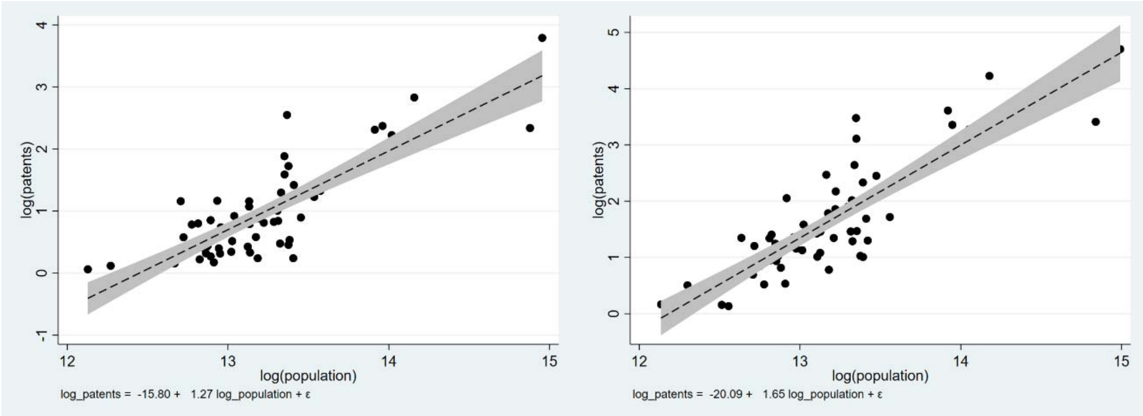


Switzerland



Sweden

2000-2007 2008-2014



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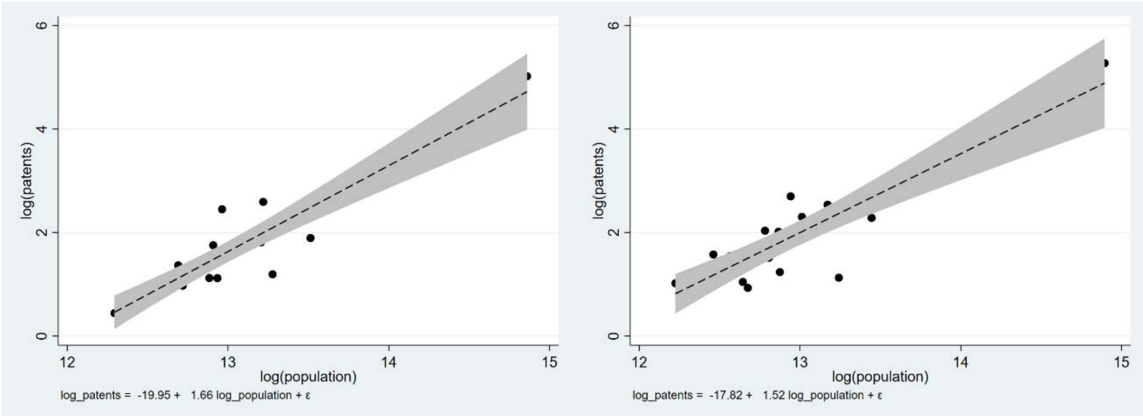

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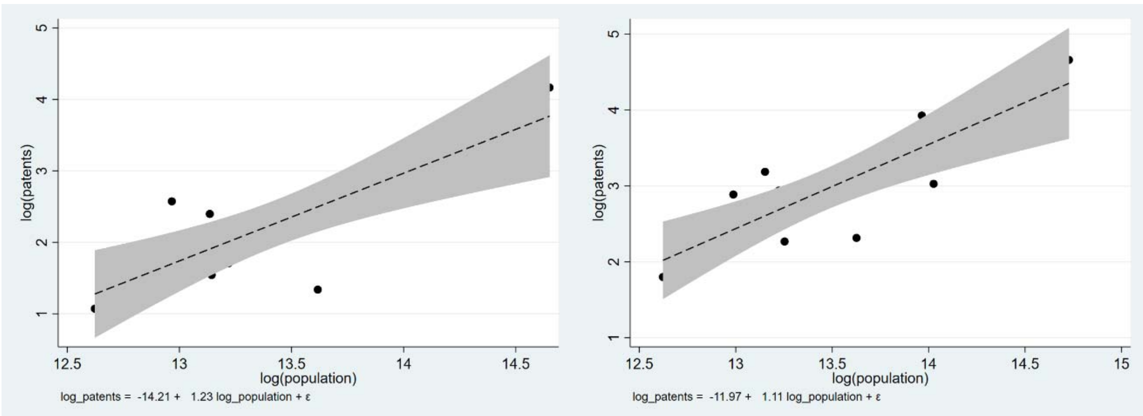
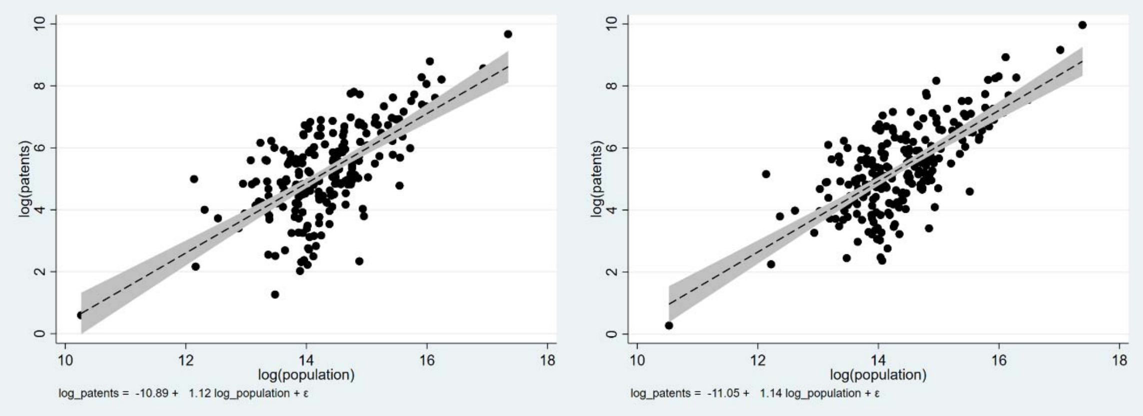


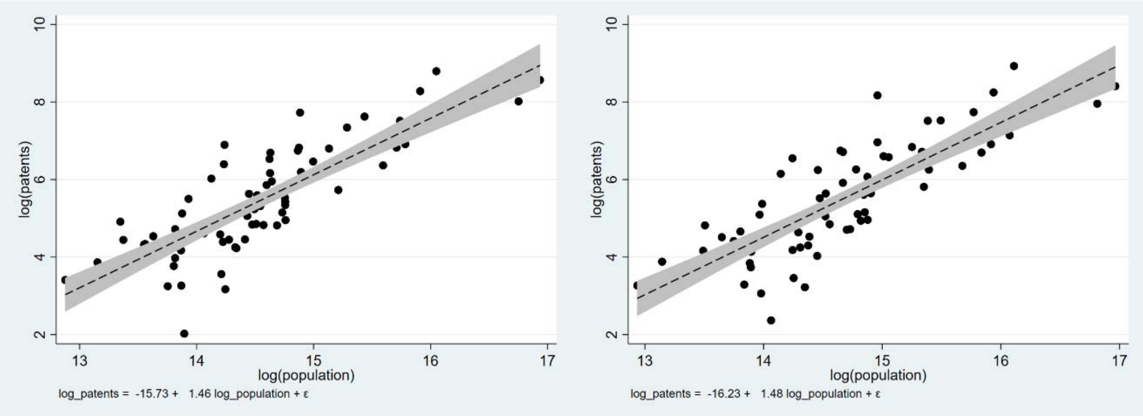
Czech Republic

Figures A2: Scatterplots urban scaling across metropolitan regions with more than 500,000 population only

2000-2007 2008-2014



All 14 OECD countries



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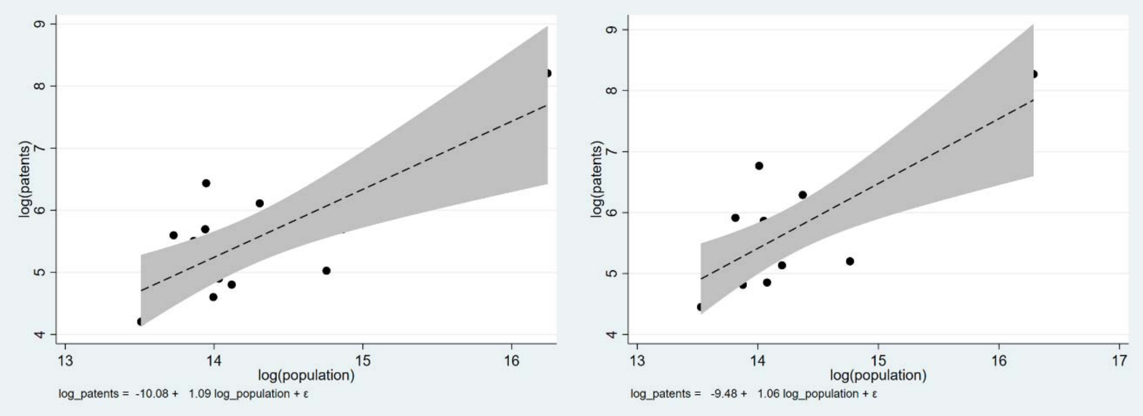
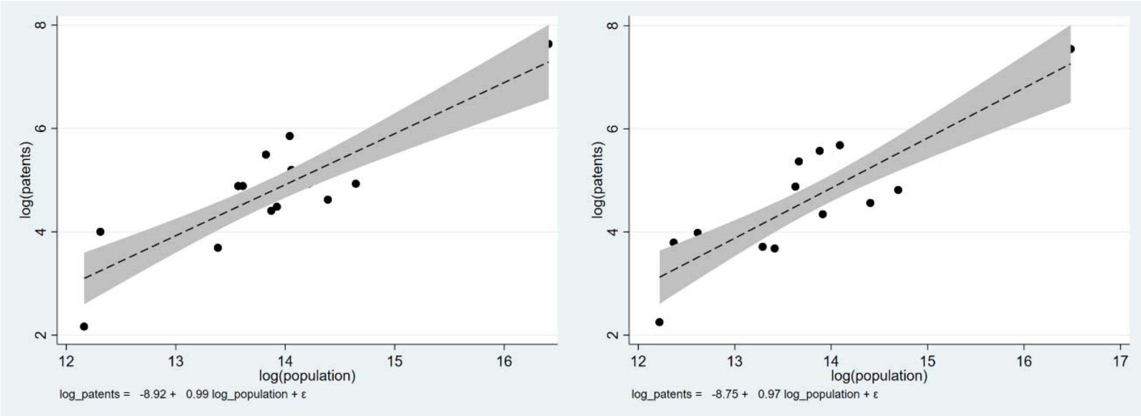
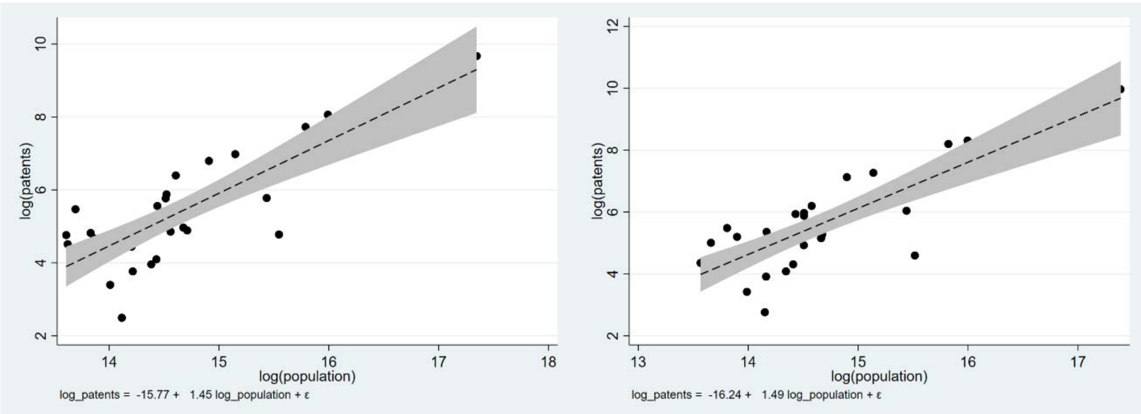


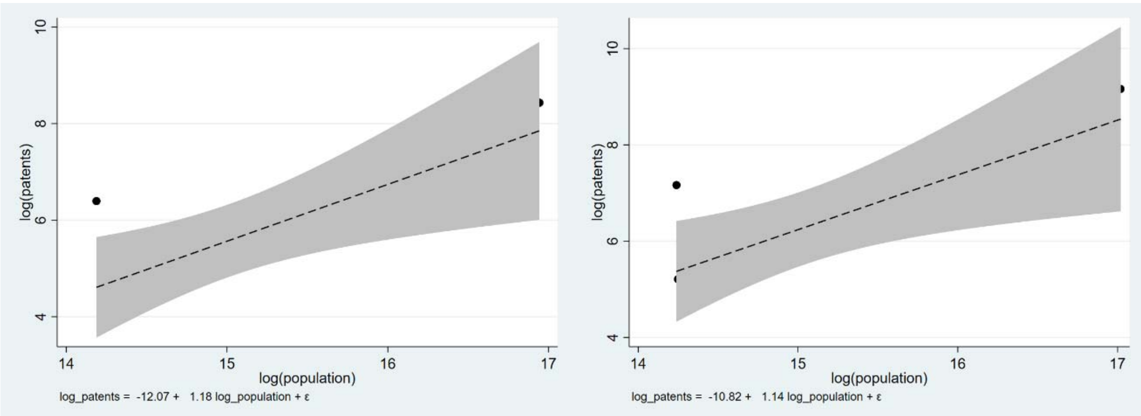
France



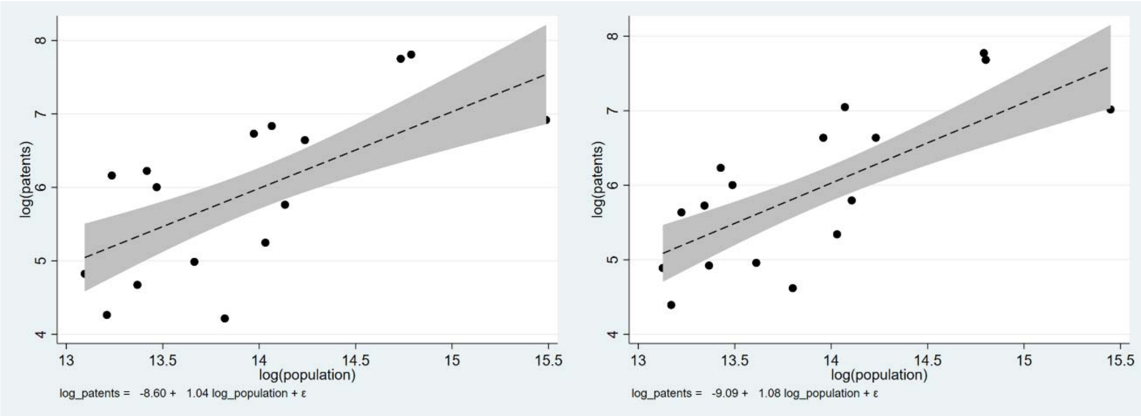
UK



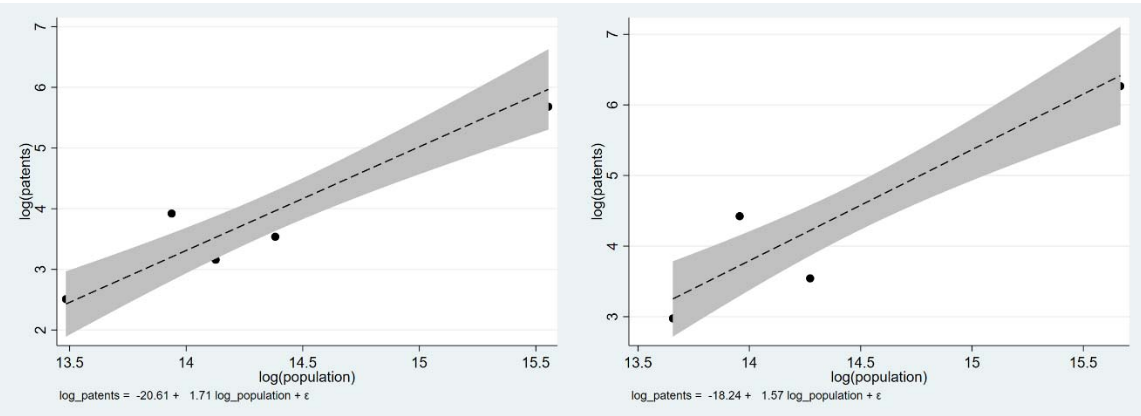
Japan



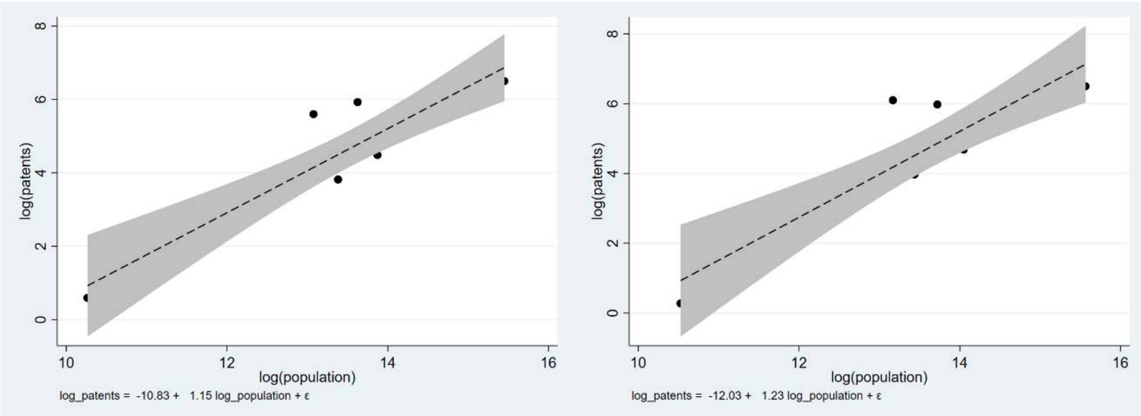
South Korea



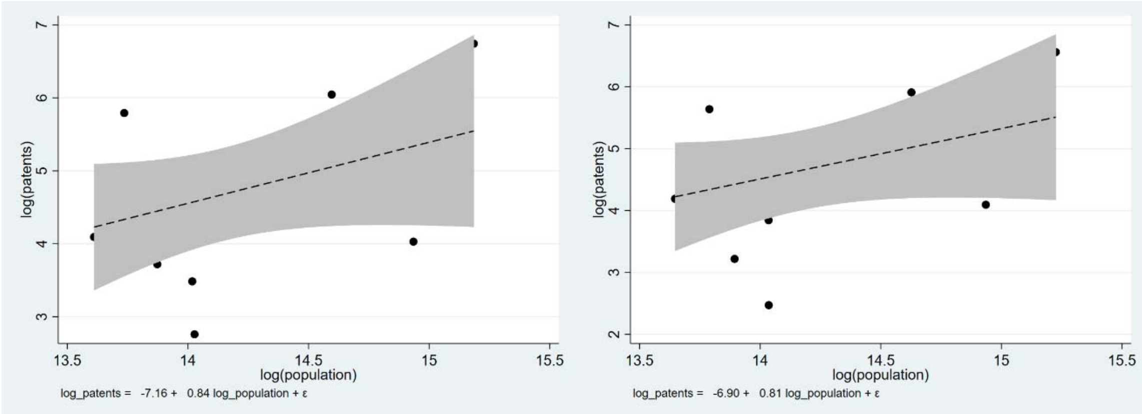
Germany



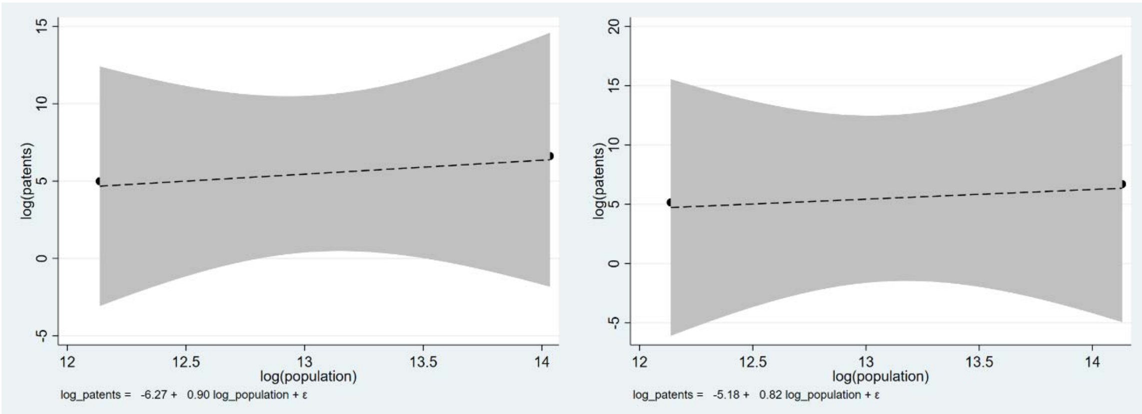
Spain



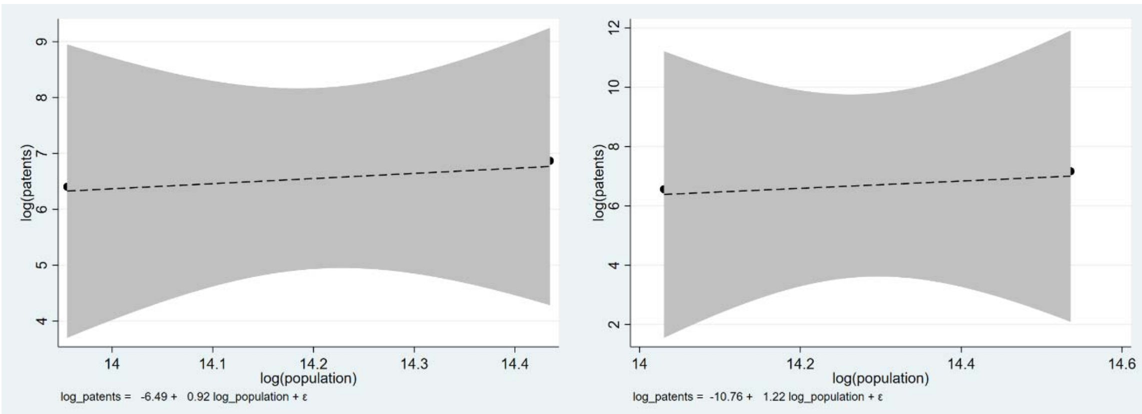
Canada



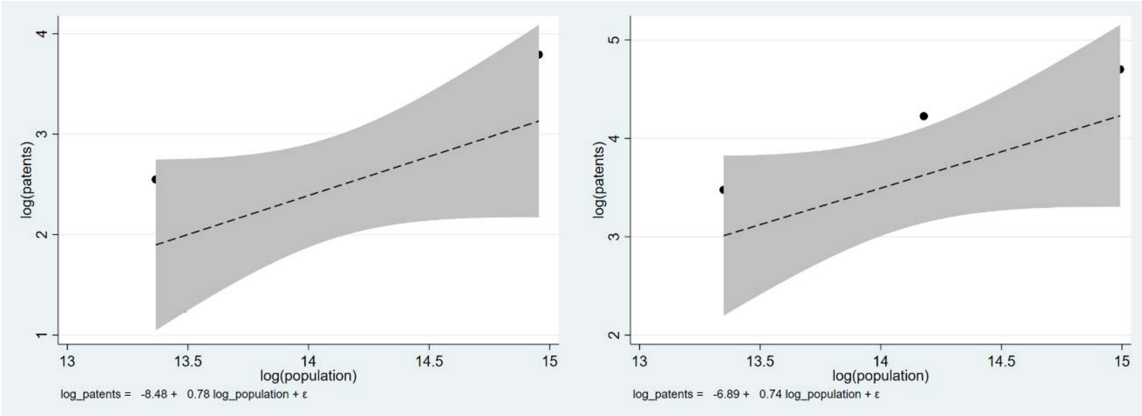
Italy



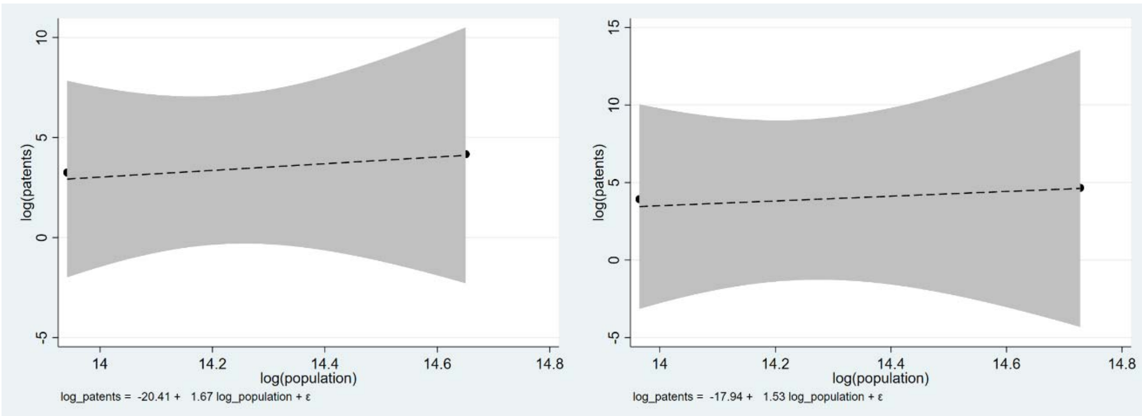
Switzerland



Sweden



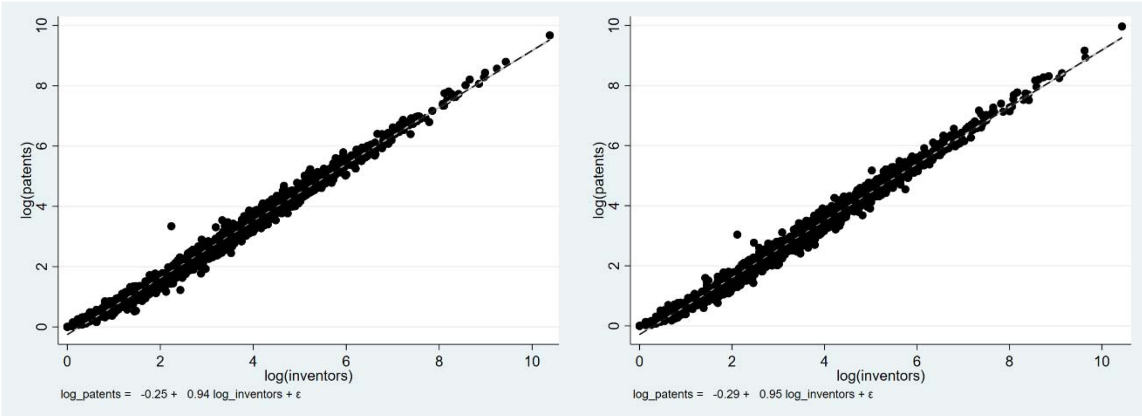
Poland



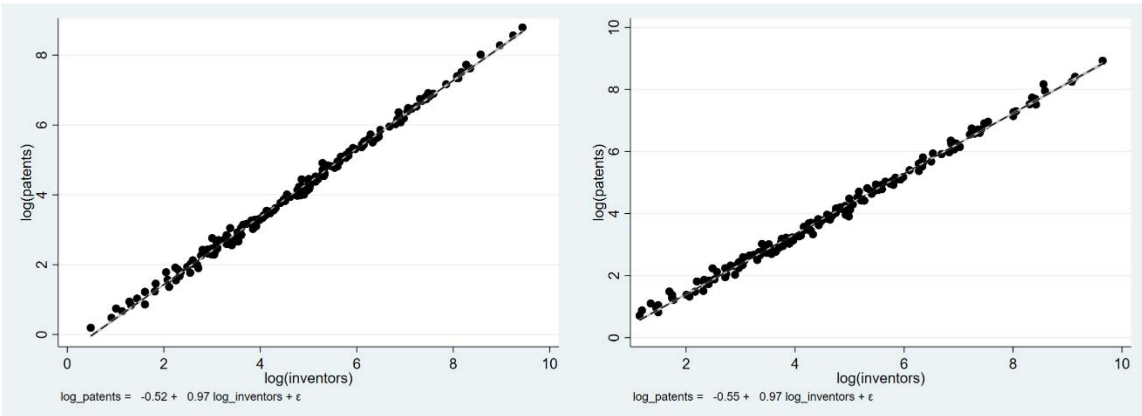
Czech Republic

Figures A3: Inventor productivity across regions

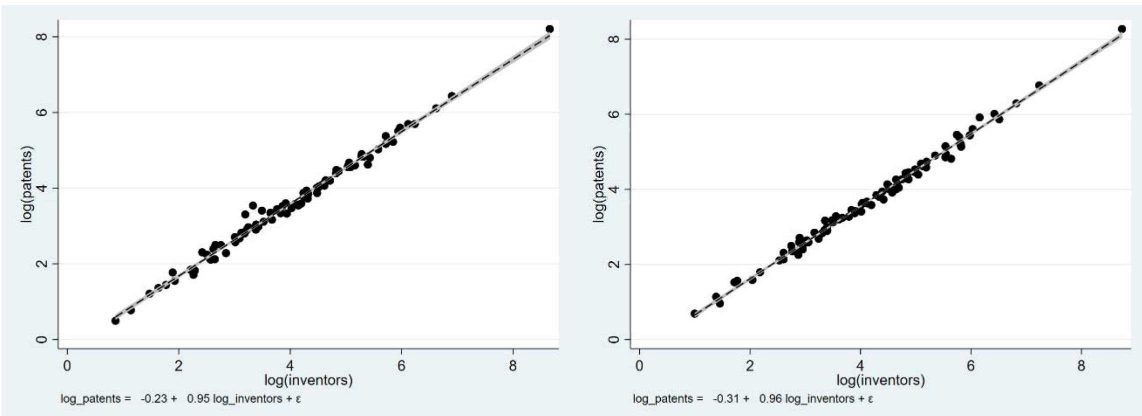
2000-2007 2008-2014



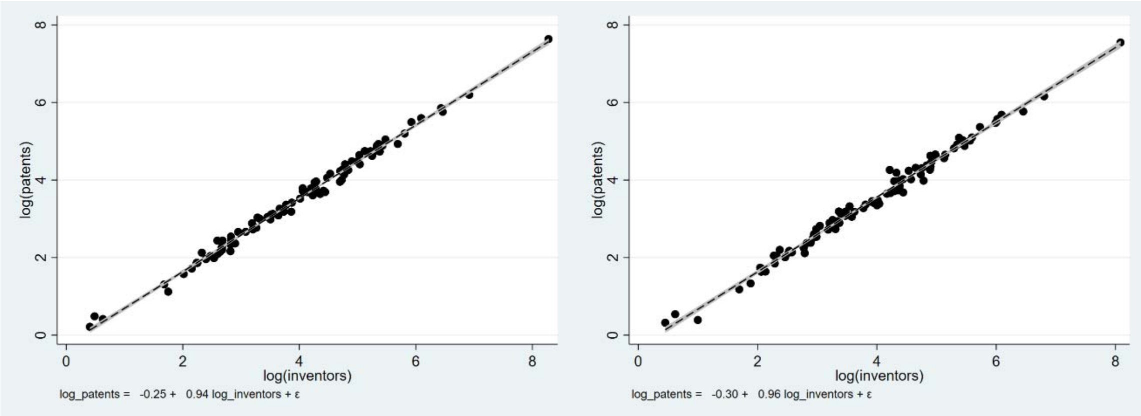
All 14 OECD countries



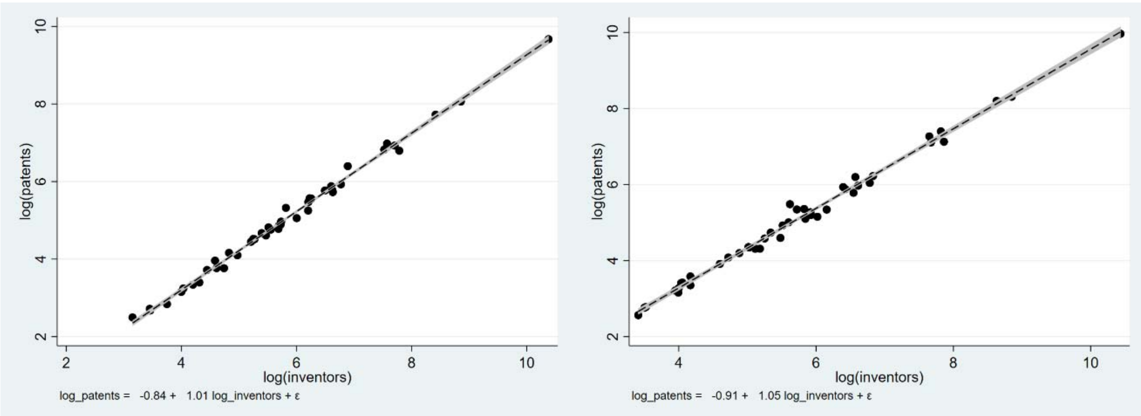
USA



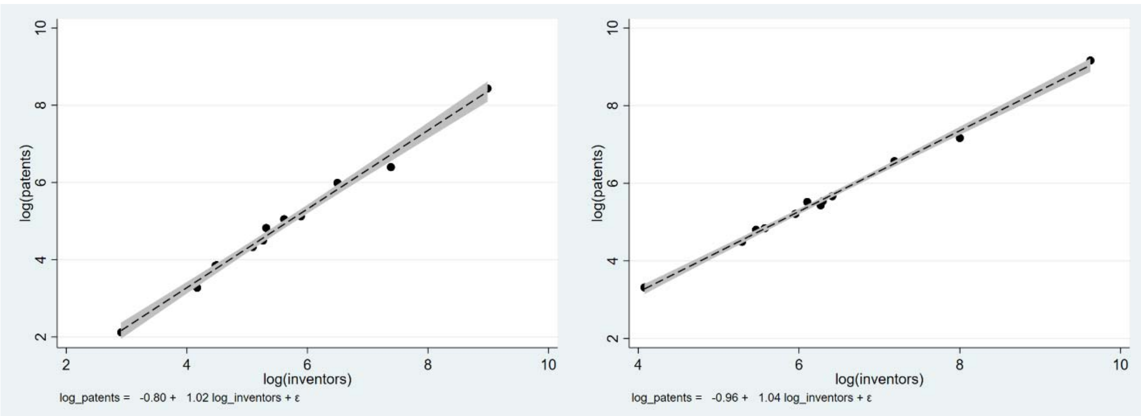
France



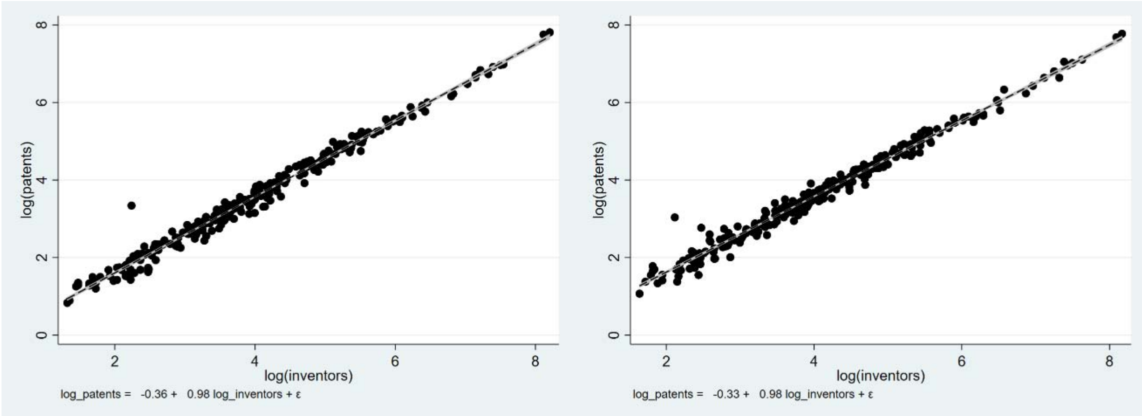
UK



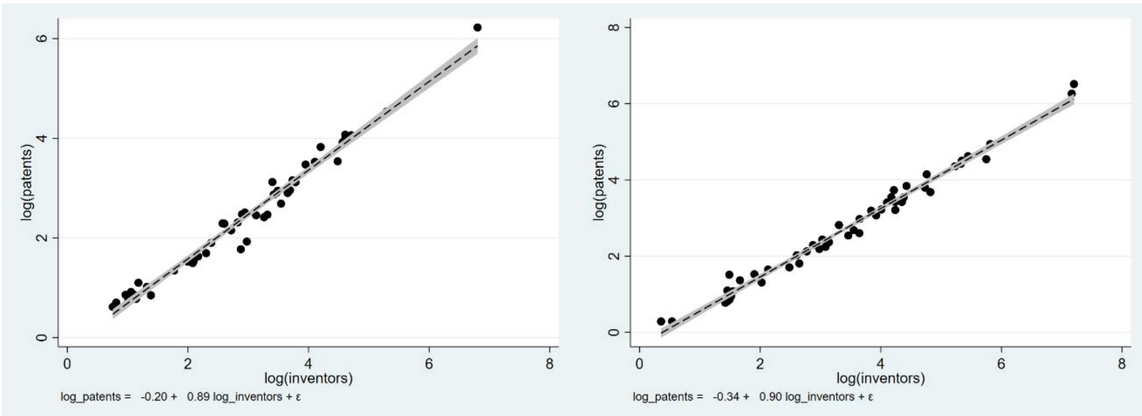
Japan



South Korea



Germany



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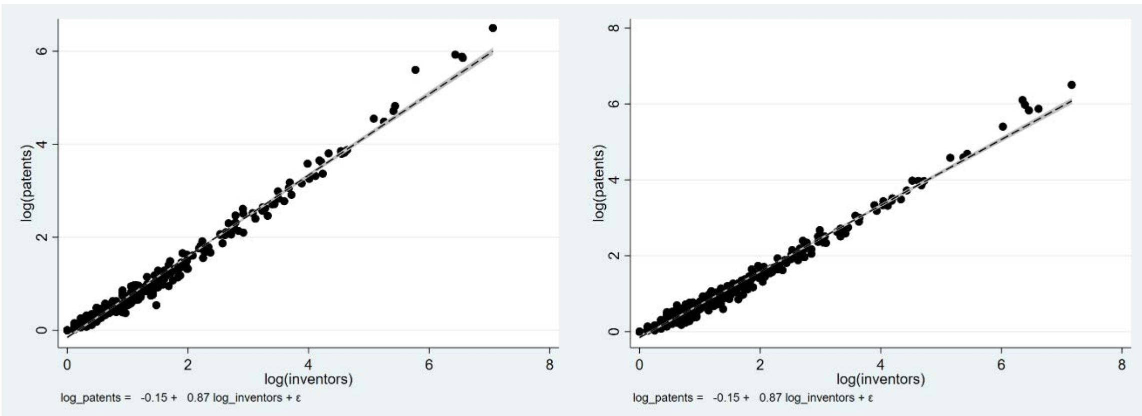
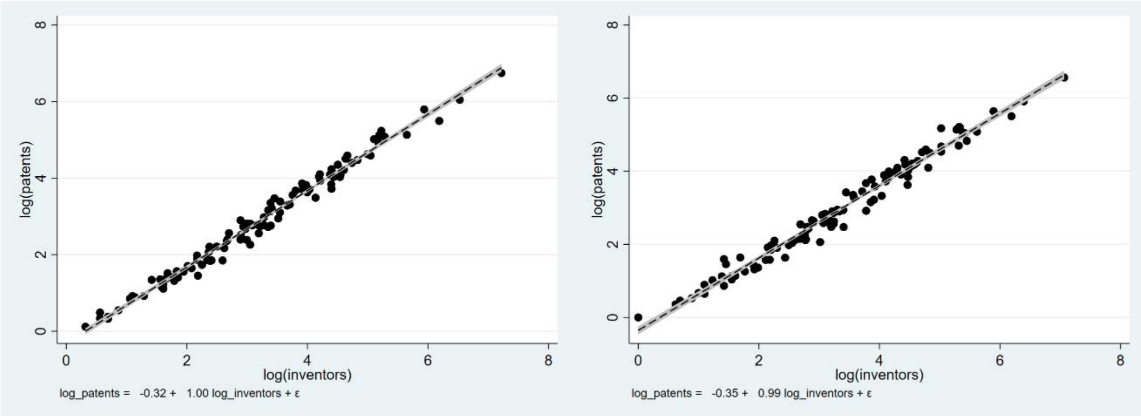
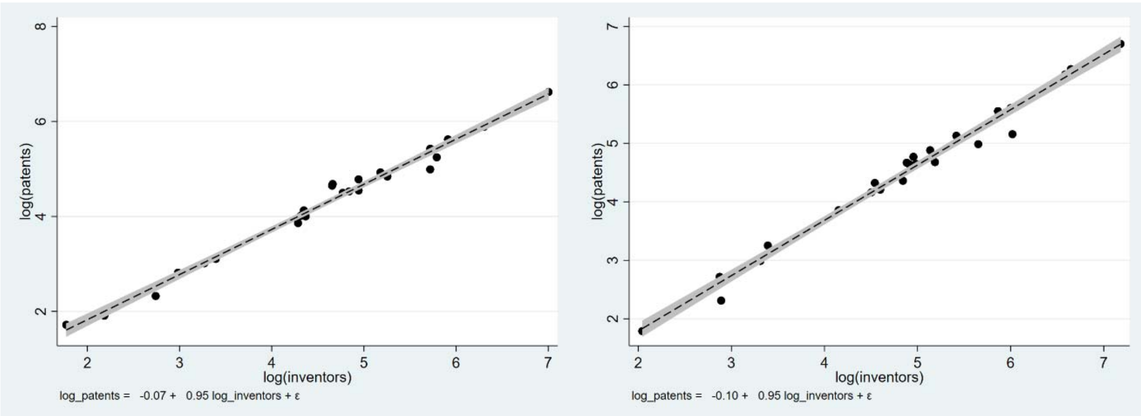


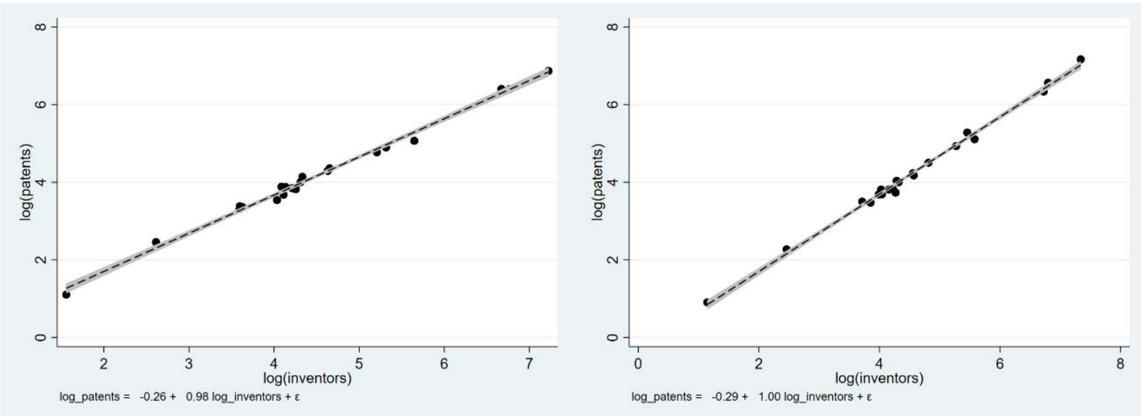
Canada



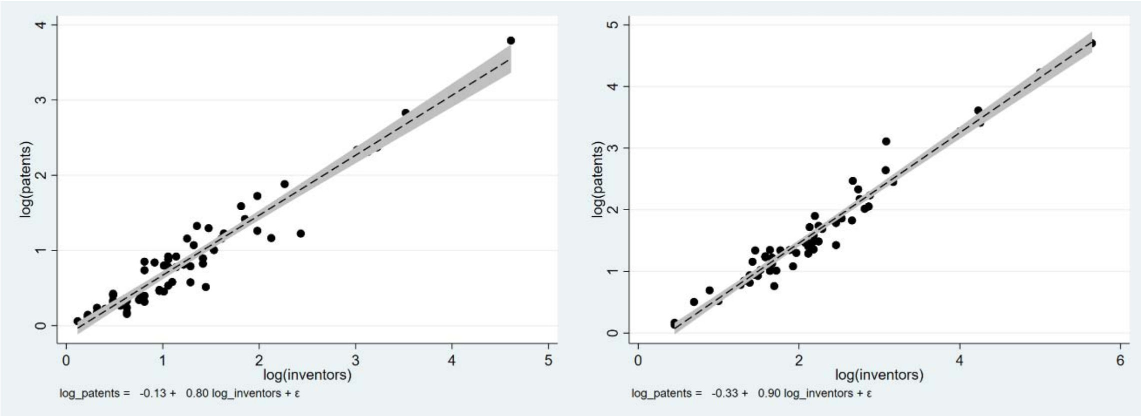
Italy



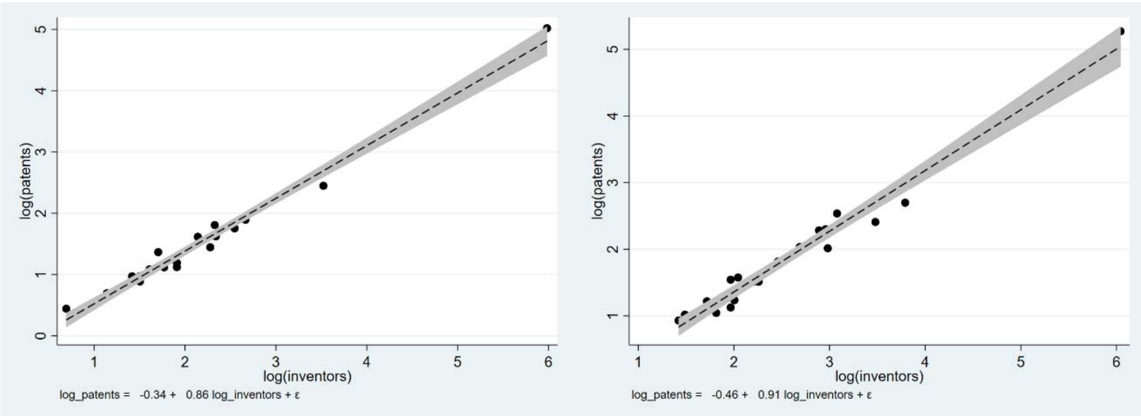
Switzerland



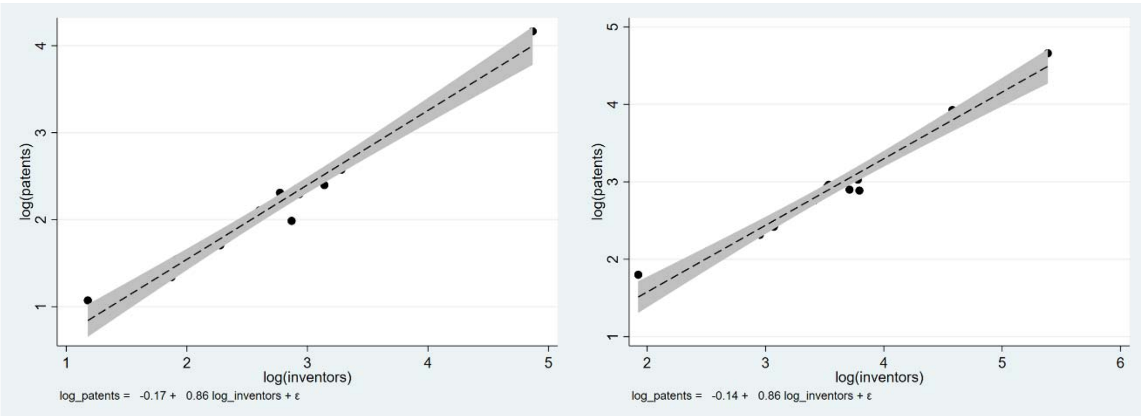
Sweden



Poland



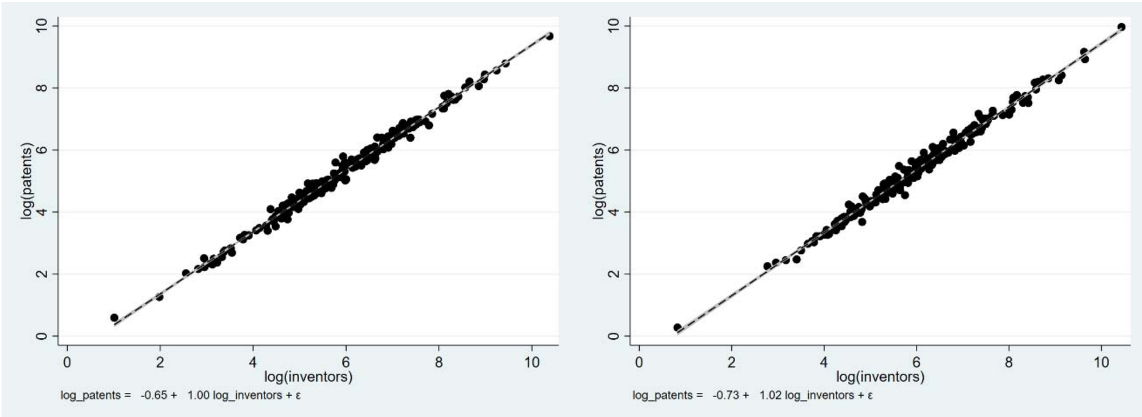
Hungary



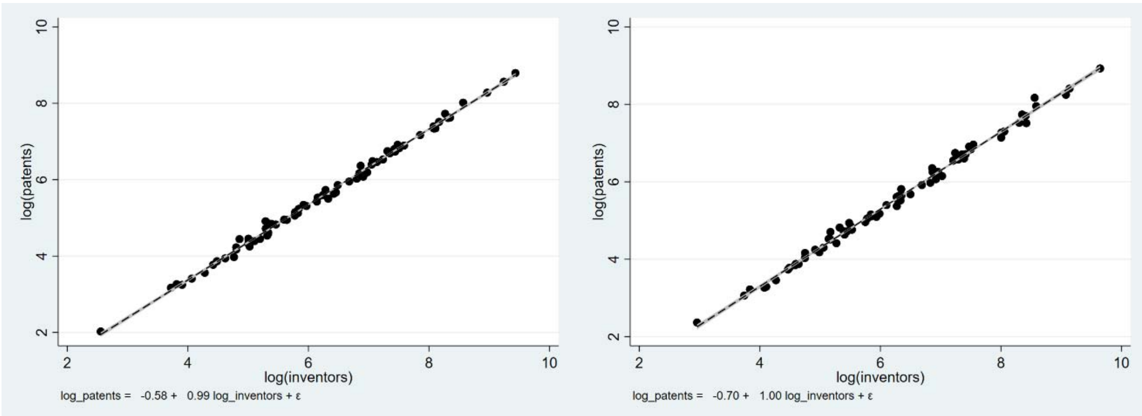
Czech Republic

Figures A4: Inventor productivity across metropolitan regions with more than 500,000 population only

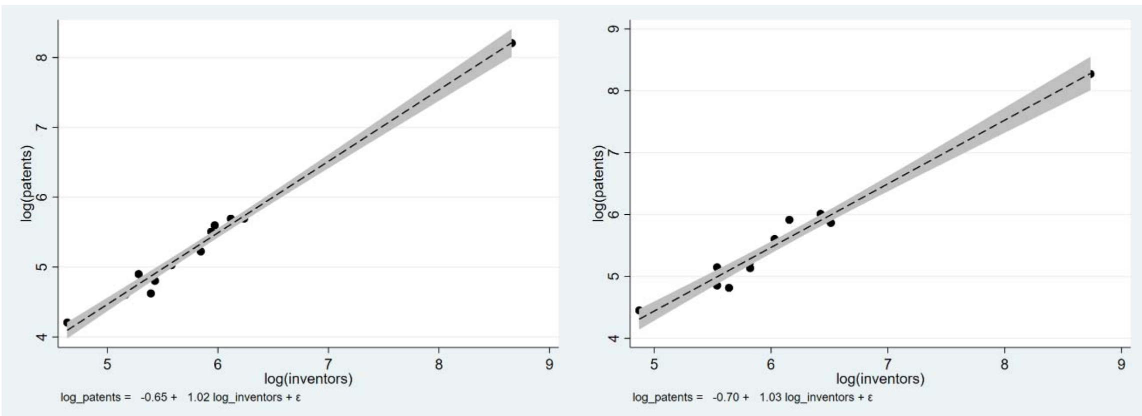
2000-2007 2008-2014



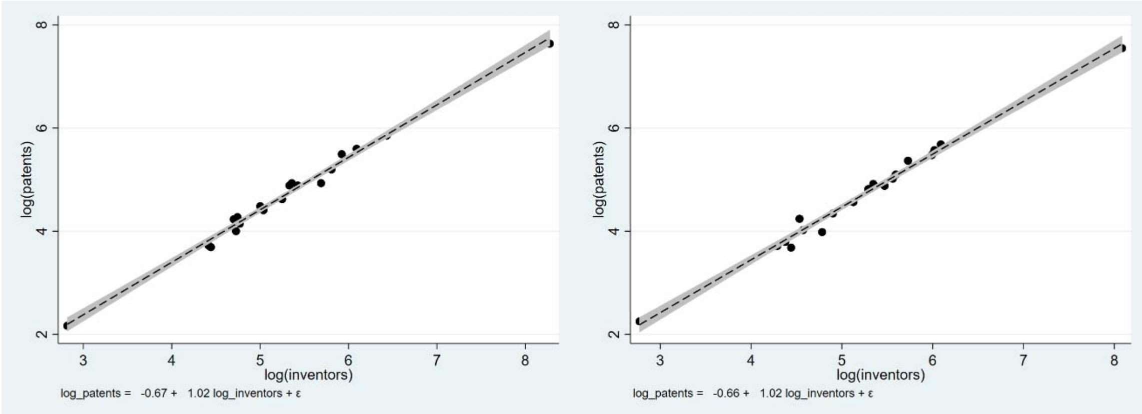
All 14 OECD countries



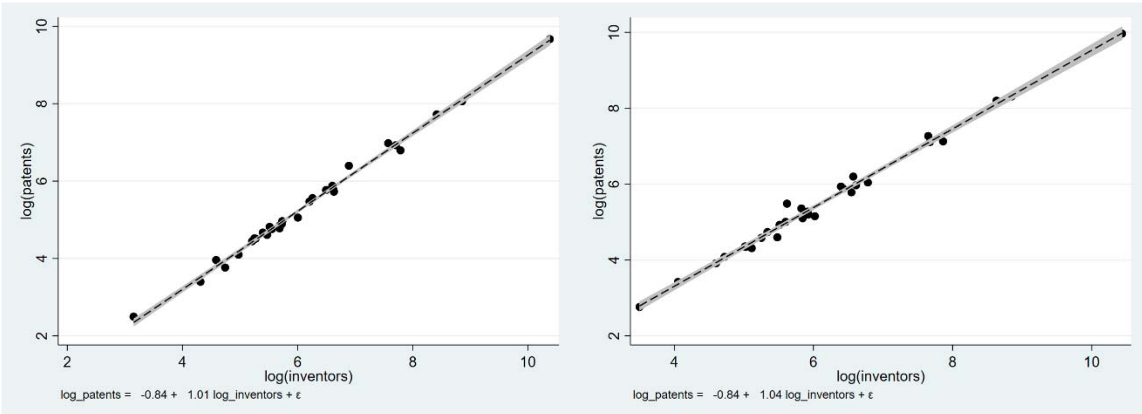
USA



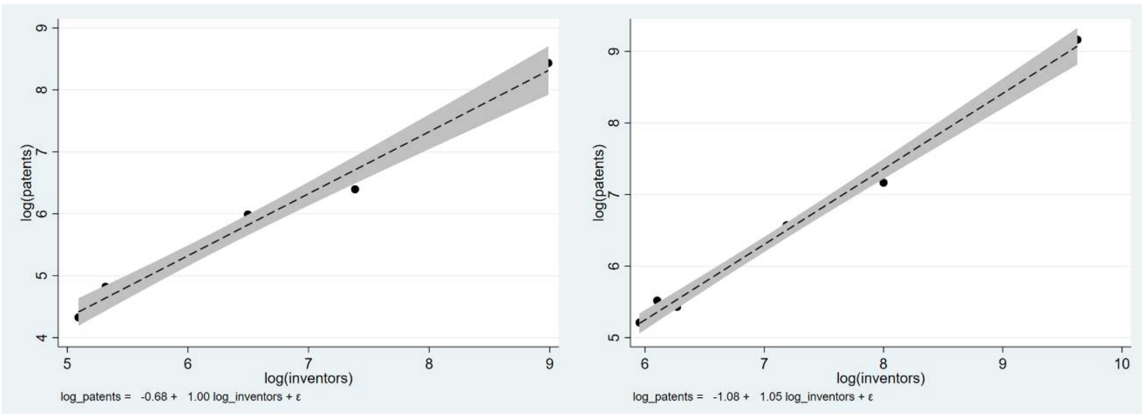
France



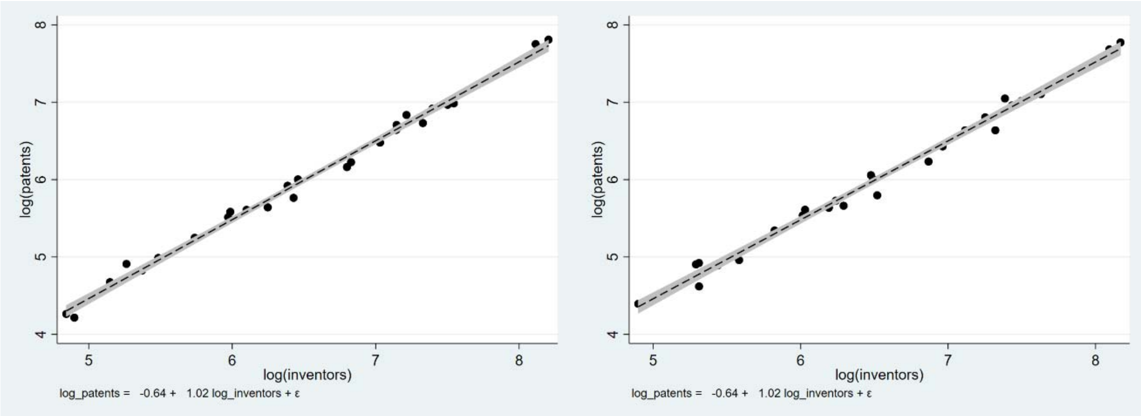
UK



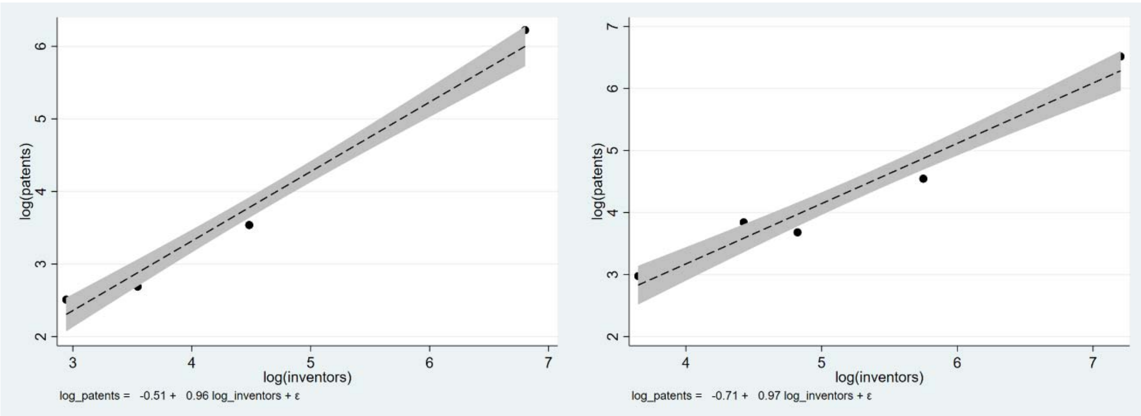
Japan



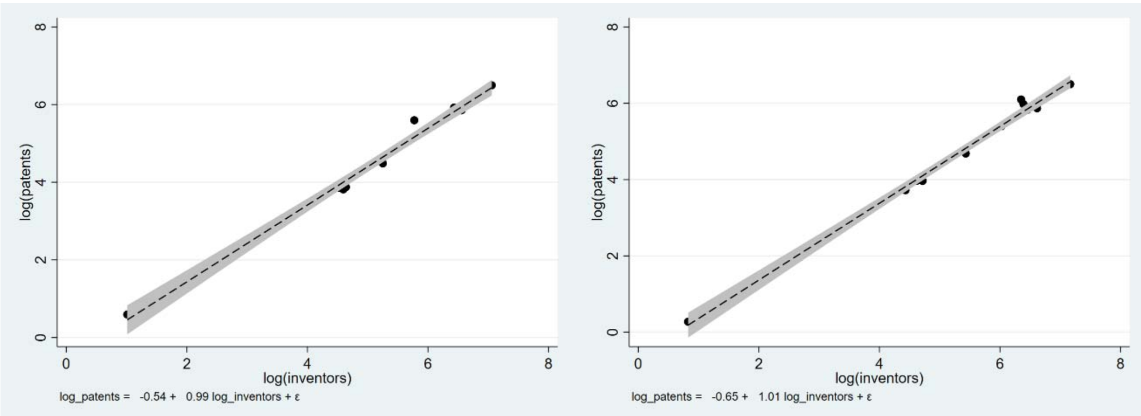
South Korea



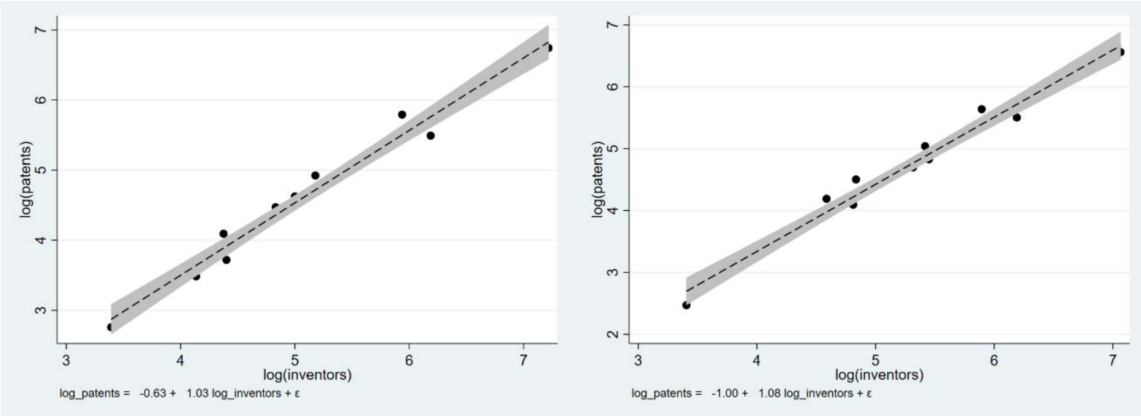
Germany



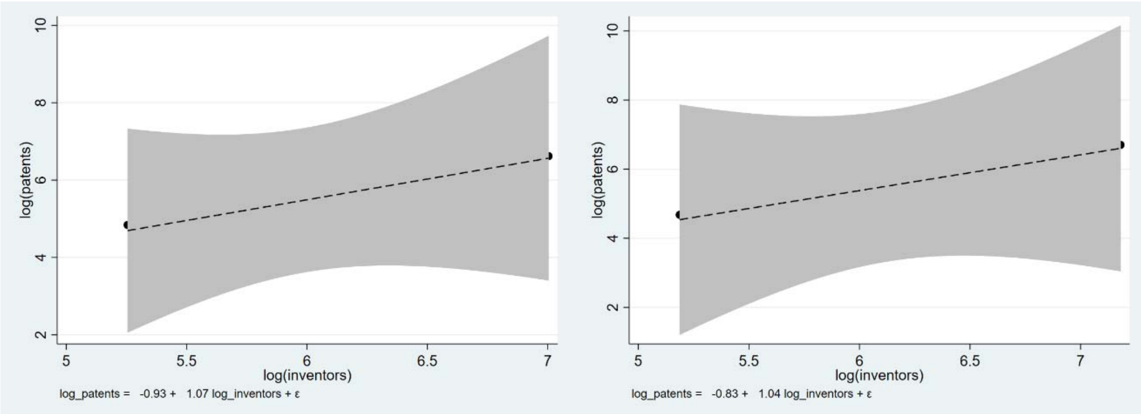
Spain



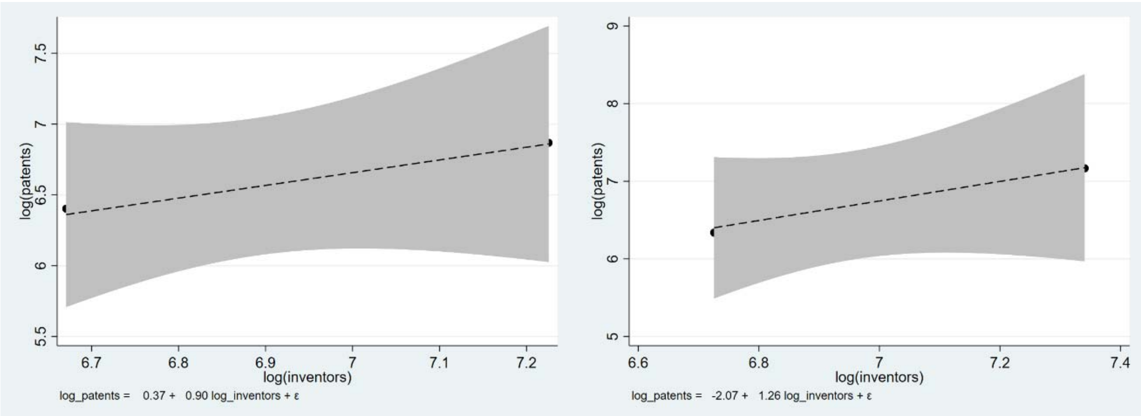
Canada



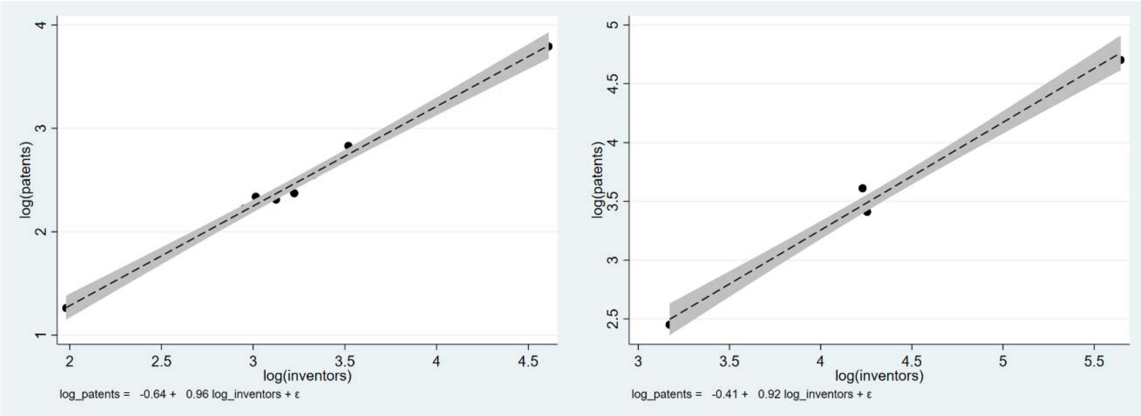
Italy



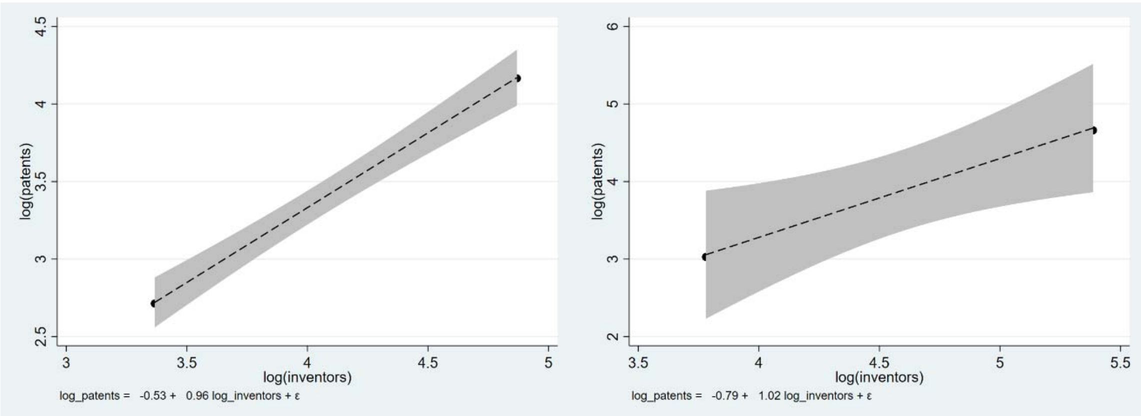
Switzerland



Sweden



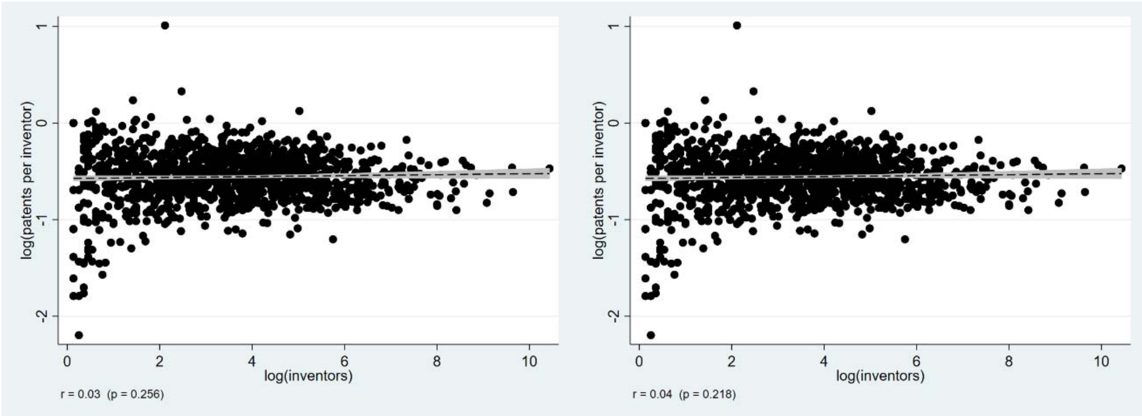
Poland



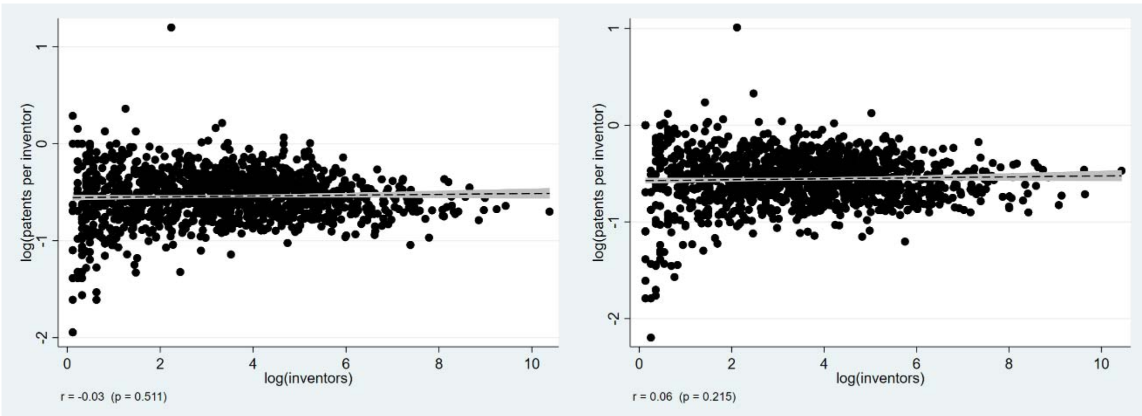
Czech Republic

Figures A5: Number of inventors and patents per inventors

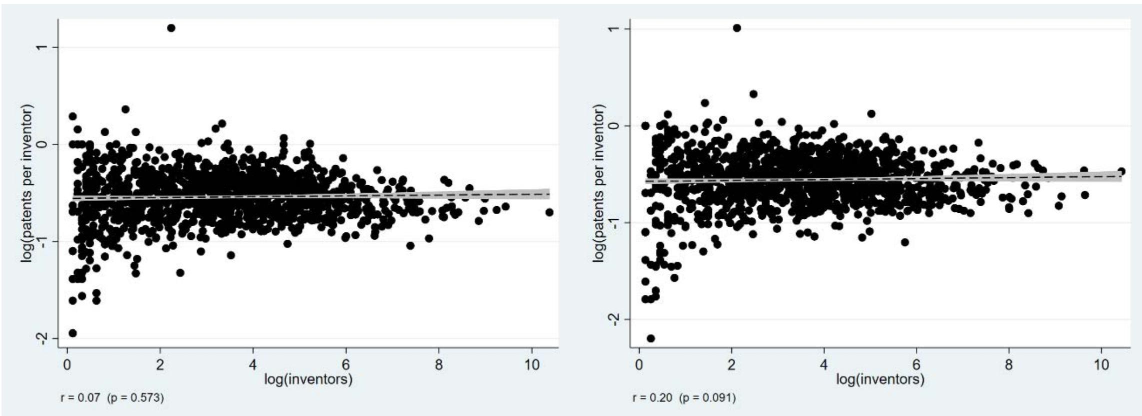
2000-2007 2008-2014



All regions



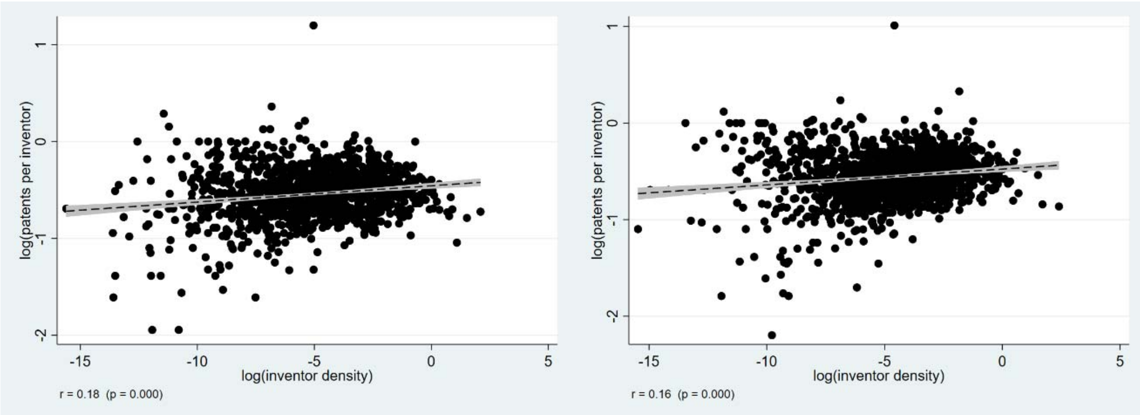
Small and medium sized metropolitan regions



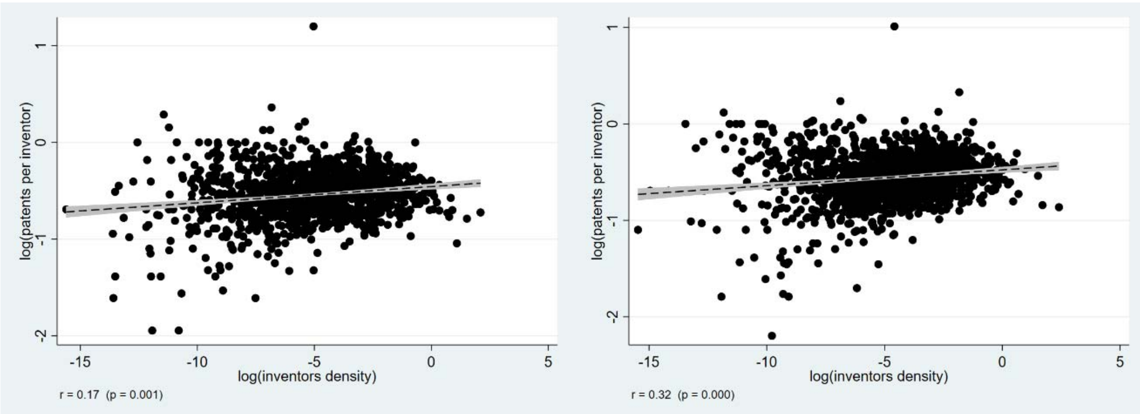
Large metropolitan regions

Figures A6: Density of inventors and patents per inventor

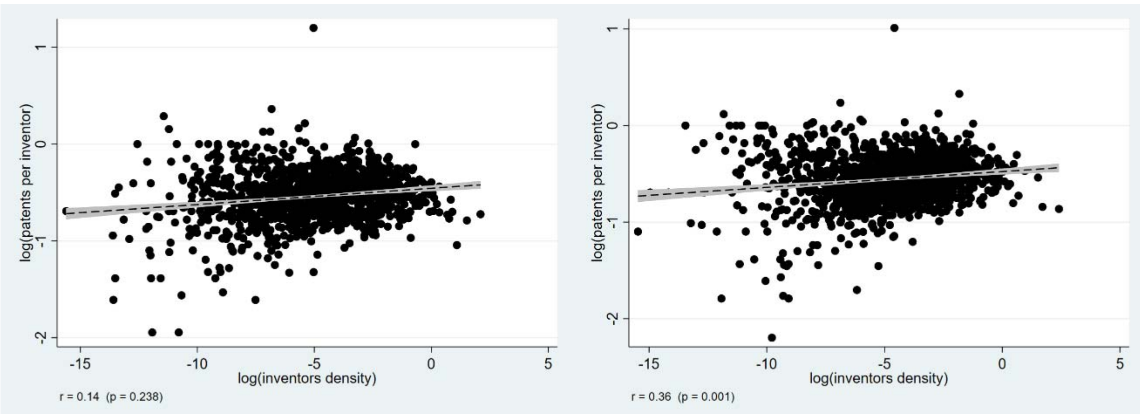
2000-2007 2008-2014



All regions



Small and medium sized metropolitan regions



Large metropolitan regions