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The Geography, Determinants, and Effects of Innovation

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Abstract

Endogenous growth theory has long recognized innovation as one of the key drivers of economic growth. Understanding what factors encourage or discourage innovative activities and how these affect our society is therefore critical to inspire policies that promote inclusive growth. My dissertation aims at broadening our comprehension of the innovative process and its consequences. The first chapter shows that knowledge intensive activities cause an increase in income segregation within U.S. cities and proposes a framework that can be used to study how to mitigate this effect. In the second chapter, I explore the relationship between population density and innovation. More densely populated places promote the development of inventions that are based on atypical combinations of knowledge. Finally, the third chapter describes a newly assembled data set of geographically referenced historical patents that will allow researchers to get a long run perspective and better understanding of the innovation process as a whole.

1 Income Segregation and Rise of the Knowledge Economy

Over the past 40 years, the economic activities that rely on non-manual and non-routine technical skills, scientific knowledge, and intellectual creativity have become the main engine of economic prosperity in advanced countries (Powell and Snellman, 2004; Moretti, 2012). Since 1975, the share of value added generated by knowledge-intensive sectors in the United States has increased by almost 15 percentage points, and the number of patents per capita issued by the United States Patent and Trademark Office (USPTO) has doubled (Figure 1). The same trend is observed when considering several other measures of knowledge intensity, including educational attainment, number of scientific publications, ratio of intangibles to assets, and share of workers employed in R&D activities and creative sectors. Proposed explanations for this structural shift include globalization, automation of routine jobs, and the steady increase in the burden of knowledge that requires an ever-increasing number of R&D workers to sustain a constant productivity growth (Jones, 1995; Jones, 2009).

This trend is believed to be associated with major social and cultural changes. Individuals with different educational levels, abilities, and social connections have been differentially

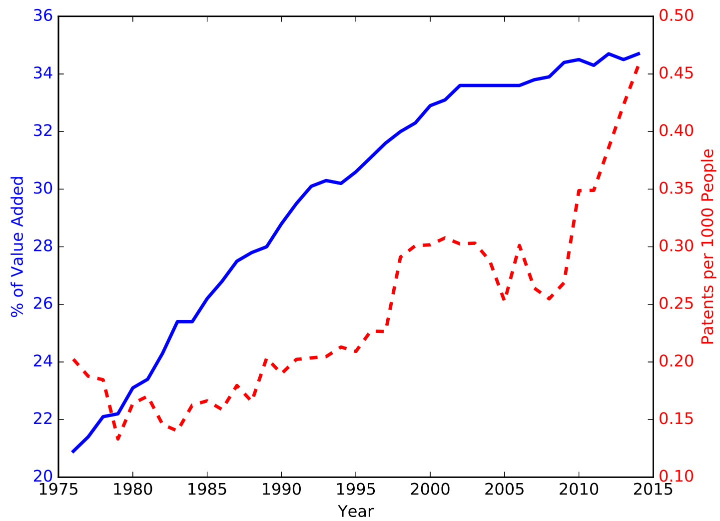

Figure 1: The blue line is the contribution to U.S. GDP (value added) of computer and electronic products, electrical equipment, appliances and components, information, finance and insurance, professional and business services, educational services, health care and social assistance, arts, entertainment and recreation (data from the BEA). The dashed red line is the number of patents per 1,000 people issued to U.S. inventors by the USPTO.

exposed to the opportunities offered by this new economic landscape and, as a result, have experienced diverging economic fortunes. Moretti (2012) argues that the geographical dimension is the most striking aspect of this divergence. Florida (2002) proposes that the rise of the "creative class" has allowed and induced waves of gentrification and re-urbanization of metropolitan cores, as well as the development of specialized innovation clusters in suburban areas. The reorganization of production and consumption activities within cities, driven by supply factors, such as thick labor markets and knowledge spillovers (Glaeser and Gottlieb, 2009), as well as demand factors, such as preferences for local amenities (Baum-Snow and Hartley, 2017; Couture and Handbury, 2017), appears to be correlated with the emergence of intellectually creative jobs in many fast-growing local economies (Florida and Mellander, 2015).

One of the most evident signs of this reorganization of the urban structure is the sharp increase in income segregation in U.S. cities. Our preferred measure of income segregation, the cross Census Tracts (CTs) within Commuting Zone (CZ) Gini index, increased by 3 Gini points over the period 1990-2010, closely tracking the evolution of overall inequality over the same decades (Table 1). However, the extent to which the rise in income segregation in U.S. metropolitan areas reflects a causal effect of the expansion in knowledge-intensive activities remains an open question. Theoretically, there are several reasons to believe that such effect indeed exists. First, innovation and other creative jobs crucially depend on knowledge transmission, which has been shown to be strongly localized (Glaeser et al. 1992; Jaffe et al., 1993; Carlino and Kerr, 2015). An increase in the returns of accessing new ideas makes geographical clustering more convenient. Second, workers in the knowledge economy tend to be disproportionately sensitive to urban and social dimensions, such as quality of schooling and social interactions, which are often strictly local in nature.

Uncovering the fundamental causes of the increase in urban segregation is of great importance. Several studies have shown segregation to have a first-order effect on several outcomes, including schooling (Katz, Kling and Liebman, 2001; Baum-Snow and Lutz, 2011), health (Acevedo-Garcia et al., 2003; Alexander and Currie, 2017), and inter-generational mobility (Chetty and Hendren, 2016). However, inferring the direct impact of an expansion in creative jobs is problematic because of potential reverse causation and the presence of unobservable factors affecting at the same time the explanatory and dependent variables. Examples of these factors include financial or housing shocks that jointly affect the urban environment and the ability of a geographical area to develop innovation-based activities.

In this study, we address this challenge by adopting an instrumental variable approach that exploits exogenous variation in knowledge intensity across U.S. cities. Our analysis suggests that innovation intensity is responsible for 14% of the aggregate trend in income segregation. The analysis further reveals that the effect we measure can be explained only in part by diverging income paths of initially segregated neighborhoods. A sizable part of the effect is, in fact, explained by an increase in the geographical sorting of households along the income dimension.

To measure (and instrument for) the knowledge intensity of the local economy, we use a newly assembled dataset of geo-referenced USPTO patents in the years 1975–2014. By comparing citation patterns in the early period (1975–1994) with the ones in the late period (1995–2014), we document the existence of a stable network of knowledge diffusion across geographical areas and technological classes. This persistence suggests that knowledge links established in the past are broadly orthogonal to changes in the economic environment. Using the network in combination with actual patenting in the period 1995–2004, we build a credible instrument for current innovative activities at the local level. We run an extensive set of validation exercises to address possible endogeneity concerns.

Our two-stage least squares (2SLS) results imply that a one standard deviation increase in patenting between 1990 and 2010 leads to an increase in the measured income segregation of 1.17 Gini points, equal to 40% of the overall increase in segregation over the same period of time. Educational and occupational segregation, which capture the extent to which residents of different educational backgrounds and occupations sort themselves in the city, also surges. The estimated effect is stronger for high-learning sectors (including IT and electronics) and even negative for low-learning ones, such as textiles. The IV analysis reveals that

	1990	2000	2010
Overall Gini	**42.8**	**46.2**	**47.0**
Across CTs - Within CZs (Segregation)	**19.5**	**20.6**	**22.5**

Table 1: The overall Gini is obtained from the FRED website. The data sources and methodology for the segregation measure are explained in the text.

the bias in the OLS estimates is negative. The direction of the bias suggests that unobserved shocks affecting at the same time segregation and innovation tend to operate on the two variables in opposite directions overall. Financial shocks that generate widespread housing and neighborhood dismantlement are possible examples.

The results can be explained as the outcome of two (related but) inherently different phenomena. On the one hand, an increase in inequality in a metropolitan area that is perfectly segregated induces a one-to-one increase in measured segregation (we will refer to this case as the *inequality effect*). On the other hand, measured segregation can increase even in the absence of any change in overall inequality, provided that residents relocate closer to other people with a similar level of income (we will refer to this second case as the *sorting effect*). The analysis strongly supports the latter as the primary cause of the innovation-driven increase in urban segregation, with the former only explaining a limited portion of it.

In the second part of the paper, we explore two possible mechanisms. First, we argue that innovation shocks increase the returns from local learning externalities and generate incentives for firms to cluster in space to benefit from them. As a result, high-education, high-salary workers relocate their redidence close to these areas to reduce commuting costs, thereby affecting residential segregation. We provide evidence that employment in knowledge-intensive occupations becomes more geographically concentrated in those cities that experience larger innovation shocks. Second, we propose that the endogenous response of residential amenities plays an important role in amplifying this effect. Consistent with this interpretation, we find that the impact is significantly stronger in cities whose variation in residential amenities is not anchored to persistent or natural amenities. The magnitudes of the estimated effects suggest that localized knowledge spillovers and residential amenities play an important role in linking innovative activities to income segregation.

To quantitatively disentangle the relative importance of these two forces in determining the trends in segregation observed in the data, we build a general equilibrium model of the internal structure of cities in the spirit of Ahlfeldt et al. (2015) – ARSW hereafter – that embeds endogenous amenities and productivities. We extend the ARSW model by introducing heterogeneity in workers' occupations: workers in creative occupations enjoy local learning externalities that are directly affected by a city-wide knowledge shock, whereas workers in non-creative occupations have stagnant productivity that is unaffected by the surrounding economic activity. Both types of workers receive local residential externalities that are determined by the density and background of their neighbors.

We illustrate the relevance of the model for policy analysis by running four counterfactual exercises that simulate the impact of four Chicago-based bids for Amazon's new headquarters. Our simulations suggest that although some high-knowledge workers relocate to the high-amenity neighborhoods on the lakefront in all four scenarios, the location of the campus has a sizable effect on the development of the surrounding neighborhoods, and on the overall increase in income segregation. The impact on segregation is the smallest when the campus is located in the southern part of the city, as it attracts high-salary workers where low-income neighborhoods currently prevail.

2 The Geography of Unconventional Innovation

The idea that informal interactions are central to innovation and knowledge diffusion has become a cornerstone of recent theories of economic growth (Lucas, 1988). This idea implies that economic geography, by determining the extent of those interactions, should play a first-order role in the creation and diffusion of knowledge. A sizable literature has built on this intuition to emphasize the role of cities and agglomeration in driving technological progress and growth (Glaeser et al., 1992; Black and Henderson, 1999; Glaeser, 1999).

In this paper, we empirically examine the link between density and innovation using narrowly geo-referenced information on patenting activity in the United States. Our geographically disaggregated data show that the advantage of cities in producing innovation is more nuanced than commonly believed. While suburban areas are responsible for a substantial share of overall innovation activity, high-density places disproportionately generate innovation with a high degree of unconventionality. This finding reconciles the intuition that density fosters creativity with the observation that the place of innovation in the U.S. is far from being limited to dense urban areas. We then propose a spatial theory of a knowledge-based economy that is consistent with our findings. The theory highlights a novel rationale for why economic activity agglomerates in places of different density and degree of diversification. This rationale is grounded in the process of knowledge creation and reconciles the tension between returns to local specialization (Marshall, 1890) and returns to diversity (Jacobs, 1969) without relying on agents whose productivity is ex-ante heterogeneous. While existing spatial theories of innovation and knowledge diffusion have focused on explaining heterogeneity in size (Davis and Dingel, 2018) or diversification (Duranton and Puga, 2001), our model can account simultaneously for both dimensions, as well as their empirical relation, opening up novel insights for policy analysis. We show that a system of place-based subsidies can have a significant impact on aggregate welfare by changing both the intensity and composition of innovation activity.

The empirical analysis is based on the universe of patents granted by the USPTO in the years 2002-2014 georeferenced at the County Sub-Division (CSD, henceforth) level. At this narrow level of geographical disaggregation, the concentration of innovative activities in high-density areas appears to be smaller than commonly thought. Over 80% of the patents in our sample originates from geographical units with density below 1,600 people per square kilometer.[1] The relationship between patenting per capita and density of population is non-monotonic, peaking around the density of San Jose and declining for higher levels of density.

However, a closer look to the data reveals a more nuanced connection between density and innovation outcomes. First, innovation produced in densely populated areas is more likely to be built upon unconventional combinations of prior knowledge. To show this fact, we propose a notion of technological distance, based on the observed network of patent citations, that proxies for the intensity of idea flows between fields. We develop an algorithm in the spirit of Uzzi et al. (2013) to evaluate the atypicality of the references listed in each patent. Our measure compares the observed frequency of each pairwise combination of citations with the frequency one would expect if references were distributed at random. This procedure assigns an index of conventionality (*c-score*) for each citation pair: combinations are conventional if their empirical frequency is large compared to their random frequency. The c-score ranks inventions along a dimension that is economically meaningful: unconventional patents are significantly more likely to be highly cited compared to conventional ones, and significantly less likely to be produced by large, publicly traded firms. We find that unconventional innovations disproportionately originate from densely populated areas. This relationship is statistically and economically significant, emerges both in patent-level and CSD-level regressions, and is robust to a wide variety of specifications.

Second, dense cities host a more diversified pool of learning opportunities. Computing the technological distance between any pair of patents produced in each CSD, we find that pairwise combinations of inventions in high-density CSDs are more technologically distant than combinations in low-density ones. Therefore, inventors in dense cities are more likely to be exposed to ideas from distant backgrounds. This higher degree of local diversification can translate into a higher degree of unconventionality provided that the local pool of innovation is a predictor of the technologies combined into new inventions. To verify this, we adopt a difference-in-difference strategy and look at the patenting activity of pre-existing firms upon arrival in town of companies in different technological fields. We find that such arrival significantly biases the citation behavior of pre-existing entities toward the field of the incoming firm. To the best of our knowledge, this paper is the first to provide direct evidence of inter-sectoral

[1] In 2005, the density of population of San Jose-Palo Alto was 1,549 residents per square km. The share of patents produced in CSDs with lower density is 63.4%. As a comparison, in 2005, density of population is 26,407 in the CSD of Manhattan; 7,175 in Boston; 6,514 in San Francisco; 5,588 in Chicago.

localized knowledge spillovers operating through this channel.

The facts that we document suggest an alternative interpretation of how technological change interacts with economic geography. Overall, suburban areas play a prominent role in the innovation process. Big innovative companies such as IBM or Motorola tend to perform their research in large office parks located outside the main city centers. One possible interpretation is that these companies can organize knowledge flows efficiently within the firm, and do not need to rely on casual interactions in a dense environment. By contrast, informal interactions in dense and diversified areas may become important in generating knowledge flows across technologically distant fields, since specialized *formal* networks (e.g., firms, academic departments, or research labs) may not internalize them efficiently. As a result, innovations originating in high-density areas will display more uncommon combinations of prior knowledge. This calls for a reassessment of the theoretical link between geography and innovation. In particular, a spatial model of innovation should be able to account for the simultaneous emergence of specialized clusters in suburban areas and diversified hubs in urban centers, while taking the heterogeneity of innovation into account. In the second part of the paper, we propose such a model and study its implications for place-based policy analysis.

In our setting, innovators are specialized in a specific scientific fields. They choose where to locate, balancing congestion costs and innovation opportunities. New product lines are created by combining an unconventional idea, which assembles *diversified* knowledge from multiple fields, with a conventional idea, that embodies *specialized* knowledge from a single field. Innovators have an incentive to cluster with people of similar background to benefit from *intra-field* spillovers that increase their ability to develop ideas. However, developing unconventional ideas demands interactions with inventors from different fields, which require additional search through informal channels. This friction amplifies the benefits from agglomeration in the form of *inter-field* spillovers, and implies that, in equilibrium, diversified cities are more densely populated than specialized ones.

The model reproduces the geographical sorting of innovation activity observed in the data. The complementarity between conventional and unconventional ideas leads to the emergence of asymmetric sites, both in terms of density and specialization. Densely populated cities diversify and generate unconventional innovation, whereas specialized clusters emerge in low-density areas and produce conventional ideas. The equilibrium implies that composition and intensity of the innovative activity are tightly related to the economic geography, and depend on the parameters of the model in an intuitive way.

This unexplored link opens up novel possibilities for welfare improving place-based transfers. Market forces produce inefficiencies in the balance between the rate of invention and urban congestion, and in the balance between the supply of conventional and unconventional ideas. We study optimal policy in this setting, and characterize conditions under which a planner would use place-based policies to increase urbanization and boost unconventional innovation. We also show that welfare gains from the optimal set of transfers are significantly larger when the planner has the ability to affect the urban structure by creating new cities and reconverting the nature of existing ones, compared to a planner who can only intervene by relocating agents within the current urban structure.

3 Comprehensive Universe of U.S. Patents (CUSP): Data and Facts

Since Hall et al. (2001), patents have been the main source of data for empirical studies on innovation and technological change. Despite the fact that patents data have been criticized as an imperfect proxy for technological input and output,[2] their easy accessibility for a large number of countries and detailed description of the invention and underlying innovation process has contributed to their popularity in the literature. With some notable exceptions (e.g., Nicholas, 2010), until recently, research papers have mostly focused on the past 50 years, or have concentrated on relatively small time frames (e.g., Moser, 2005), and specific dimensions of the data. The reason for this was the lack of a reliable data source of historical patents. The U.S. Patent and Trademark Office (USPTO) provides detailed data for all the patents issued from 1976 on, and studies that focused on innovative activities prior to this year often required the collection of data by hand.

More recently, thanks to the availability of increasingly reliable Optical Character Recognition (OCR) software, computational power, and the publication of high-quality scan of historical patents by the USPTO, various authors started projects that exploit historical data on patents. Notable examples are Akcigit et al. (2017), Sarada et al. (2017), Packalen and Bhattacharya (2015), and Petralia et al. (2016). The first two match patents data to the recently released decennial Census data and therefore mainly focus on the decades between 1880 and 1940. Packalen and Bhattacharya (2015) study the importance of physical proximity for innovation throughout history. To do so, they extract the name of the city, or county, from the text of each patent and study how the tendency of using new ideas in inventions changes with population density. Finally, Petralia et al. (2016) digitalize the images provided by the USPTO and extract information about the county of residence of inventors and assignees. The parsing of the text is supplemented with some machine learning techniques, such as neural networks, employed to measure the plausibility of the collected data, as well as to infer the values of missing observations.

Despite the important contribution of these papers, the data sets they assemble contain different sets of variables and cover different time frames. Moreover, some of these projects

[2] For example, Moser (2005) uses data from two World's Fairs at the end of the 19th century and shows that inventors from countries without patent laws focused on sectors that relied more on secrecy than patenting. This suggests that, at least in that period, patenting activity was skewed towards a certain set of industries.

do not make the data collected readily available to other researchers. The aim of this paper is to fill this gap. Three years ago, I started working on a newly assembled data set of historical patents. The idea was to collect all the variables that are commonly used in the innovation literature using a consistent methodology and data sources, and share the result with the rest of the community. Traditional sources, such as the USPTO and Google Patents, are complemented by newly digitalized patent documents and an extensive use of fuzzy matching is employed to extract information about the patent itself (e.g., technology classes, filing year, and backward citations), as well as about inventors and assignees. Each inventor and assignee is geolocated at the town level, the most disaggregated geographical level that is possible to identify from the patent text. The outcome is what I called the Comprehensive Universe of U.S. Patents (CUSP). It spans almost two centuries of patents data (1836-2015) and contains the richest set of variables available so far. Various sanity checks show a high degree of accuracy.

The first part of the paper describes in details the data sources and techniques used to extract the data. I also compare CUSP with HistPat (Petralia et al., 2016), one of the most promising data sets of historical patents made available on the Harvard Dataverse. The analysis shows a broader coverage of CUSP and a similar level of accuracy in terms of geolocation of the patents, the dimension that is most stressed in HistPat. In the second part, I report some stylized facts. Some of these facts confirm well-known patterns discussed in the literature, such as the upward trend in the average number of inventors per patent (Wuchty et al., 2007). Some others, such as the ones describing citations patterns across cities over the past two centuries, are new and might point to interesting directions for future research.

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