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LOCATION, LOCATION, LOCATION: WHY DO INVENTORS MOVE TO TECHNOLOGY CENTERS?

Dhanoos Sutthiphisal
McGill University and NBER

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I. INTRODUCTION

Scholars have long recognized that inventors are quite geographically mobile (Khan and Sokoloff, 1993; Saxenian, 2002; Lamoreaux and Sokoloff, 2005). In fact, roughly one fourth of patent applications filed by U.S. residents in 2006 have inventors or co-inventors who were immigrants (not born in the U.S.) among their creators.[1] Similarly, more than 35% of software inventors relocated during their inventive careers and, for those who did move, on average they moved four times.[2] Even in a historical context, in 1870, 1890, and 1910 more than 55% of patent holders in shoe, textile and electrical fields relocated and registered their residence in a state where they were not born.[3] In stark contrast, less than 35% of the American population of the same period was born in states (and countries) other than where they resided.[4]

Despite their high mobility across space, inventors and their ideas are often found to cluster in a few geographic areas (invention or technology centers). For example, since late 1990s residents of San Jose and Greater Boston combined together have continued to receive more than ten percents of the patents granted by the US Patent and Trademark Office to all residents of the entire country each year.[5] Likewise, in the late nineteenth century, more than thirty percents of textile and forty percents of shoe patents were created by residents of one single state – Massachusetts.[6]

[1] Wadhwa et al (2007).

[2] Schankerman et al. (2006).

[3] Sutthiphisal (2004).

[4] U.S. Bureau of the Census.

[5] Patent Technology Monitoring Team Reports, U.S. Patent and Trademark Office.

[6] Sutthiphisal (2006).

Given these stylized facts about inventors, there has been a surge of interests to understand the concentration and mobility of inventors among policymakers, and scholars from various disciplines in recent years. The discussion is centered around three important questions. First, what are the factors that motivate inventors to relocate? Second, what benefits does an inventor receive once moving into a technology center? In other words, what do technology centers offer to inventors? Last but not least, which technology policy should governments devise, so as to attract (or retain) the technologically creative? Because technological change is widely considered as the engine of growth, the answers to these questions are evidently important. In this paper we hope to provide some insights into these questions.

Prior work has suggested that a better access to new scientific and technological ideas – that is, knowledge spillovers – may play a key role in motivating inventors to relocate to technology centers. Rosenberg (1963), Pred (1966), and Saxenian (1994) argue that being in proximity to the inventive will reduce the costs of acquiring new scientific and technological ideas to carry out inventive activity.[7] Several studies, for example, Trajtenberg (2005), and Agrawal et al. (2006), have recently begun to examine the relationship between knowledge spillovers and inventor mobility. Nevertheless, a better access to information is not the only factor that may affect the location of inventors. Market coordination mechanisms for trade and investment in technology can too influence inventors' decision. Higgs (1971), Lamoreaux and Sokoloff (1999 and 2002) and Arora et al (2001) have stressed the importance of these market coordination mechanisms in raising the expected returns to invention. As these market coordination mechanisms are abundant in technology centers,

[7] Scholars (such as Romer, 1986, Lucas, 1988; and Krugman, 1991) refer to such mechanism as knowledge spillovers.

inventors may be motivated to move into the centers, so as to be close to these market coordination mechanisms and utilize them. However, whether such market coordination mechanisms indeed affect inventor mobility and location choices, and to what extent, have not been explored in prior work, nor they have been examined together with knowledge spillovers in explaining the geographic mobility or location choice of an inventor.

The paper attempts to improve our understanding of the relocation decision of an inventor, particularly moving into an invention center, and how it affects his subsequent inventive activity. Since it is virtually impossible to directly observe which factor most influences inventors to move, we instead closely examine inventors (patent holders) of particular industries with a known technology center: the American shoe and textile industries during the late 19th century. The rich biographical information in U.S. decennial census manuscripts as well as other historical records during the late 19th century allows us to trace inventors over time. We can thus infer the relative importance of the two factors that motivates inventors to relocate from their revealed preferences in terms of their residences, patenting and assigning behavior over the course of their lives.

We find that inventors benefited by relocating to an invention center from market coordination mechanisms for trade and investment in technology. Inventors who moved into Massachusetts, regardless of whether they were involved in production (low skilled) or machinery (high skilled) had a higher rate of selling or licensing (assigning) their patents than their counterparts who relocate to elsewhere. We also find some effects of knowledge spillovers, but they were not symmetrical across different groups of inventors who held jobs of different skill levels. The impact was more pronounced for inventors who were involved in machinery. Massachusetts immigrants with machinery background created more patents, generated their first patent in their respective field at a slightly younger age, collaborated

more frequently than inventors with the same occupational background but relocating to somewhere else. The other group of inventors whose jobs were involved in production, however, did not benefit from relocating to Massachusetts. The results on knowledge spillovers imply that information could only spillovers among a very specific set of inventors: those in the machinery in this case. Individuals outside this set of inventors, even the ones that were rather related to them such as those in the production, were not benefiting from the better access to technical information at the technology center.

The rest of the paper is organized as follows. Section II outlines our empirical strategy in assessing the factors that motivate inventors to move. Section III discusses our data. Section IV reports estimation and findings. Finally, Section V provides concluding remarks.

II. Empirical Strategy

Since it is virtually impossible to directly observe which factor most influences inventors to relocate, an understanding of the causes that trigger an inventor to move requires an assessment of the consequences that the inventor endures after relocation. We can thus infer the relative importance of the two reasons that motivate them to relocate, from examining the changes in their various inventive activities after relocation. In other words, we rely on inventors' revealed preferences on location to provide a clue into the underlying reason(s) why they move.

If an inventor is motivated to move to a new location, so as to access knowledge spillovers that the new location offers, we would expect such a relocation to increase the odds for the inventor to gain more technological ideas and to collaborate with others. The new opportunity to exchange ideas may take place in the technology field that the inventor

has worked for or in other fields. Thus, after the relocation, we should observe an increase in the inventor's productivity at invention, an extension of the technology fields where the inventor seeks patent protection for his inventions (patenting in different industries), and more collaboration with fellow inventors. On the other hand, if the inventor is attracted to the new location for its abundant access to market coordination mechanisms, the relocation likely improves the prospect of reshuffling resources and selling (and licensing) inventions. As the inventor can mobilize resources and extract returns by assigning (selling or licensing) the patent privilege of his invention to another party, we would expect an increase in the number of assignees and a decrease in time for his patents to be assigned after the relocation.

Nevertheless, in inferring the relative importance of the two factors from changes in patenting and assigning behaviors, we inevitably face an identification problem. Productive inventors tend to relocate more frequently, and they tend to move into technology centers. Thus, relocation does not seem to be a random process among inventors. We may observe that an inventor is highly inventive after relocating to a new location abundant with knowledge spillovers. Such a finding, however, is not sufficient to conclude that spillovers help increase his productivity at invention. He may have always been productive. [8]

We deal with such an identification problem as follows. We first trace inventors over time. However, instead of examining relocation(s) that took place during the course of one's inventive career, we focus on relocation that occurred long before one even became an inventor. Furthermore, we categorize these inventors, who did relocate long before becoming an inventor, into two groups. One group moved into the technology center and

[8] This problem is similar to the self selection problem discussed in the immigration literature. See Borjas (1994).

the other group relocated elsewhere. The career trajectories of these two groups of inventors are thus compared to identify the benefits offered by moving into the center. In other words, this strategy can be thought of as a quasi-experiment, which.randomly distributes inventors into two locations – the technology center and elsewhere. The inventiveness of inventors of the technology center and that of other locations are likely similar through the random process. Such an experiment, thus, allows us to observe advantages the technology center may offer to its residents.

III. DATA

Following prior work, we rely on patent records to identify inventors and gauge their inventive activity.[9] We examine inventors who were awarded at least one utility patent in the shoe and textile fields by the U.S. Patent and Trademark Office in 1890 and 1910. These inventors were originally collected by Sutthiphsial (2006), and there are a total of 1,158 inventors with U.S. residence in the two cross-section years.

To trace these inventors' inventive careers, we use the inventor-name search inquiry in LexisNexis (U.S. Patents) on-line database to retrieve all utility patents possibly granted to these 1,158 inventors over the course of their lives. These inventors generated a total of more than 14,000 patents over their career. For each of these patent records, we collect the title of the patent, the grant date, the file date, and the name and residence of the inventor(s) and the assignees, if any.[10] Moreover, we identify whether each of these patents are related to the shoe and textile or other industries by reading through patent documents, claims and drawings so as to be able to assess whether inventors extend their inventive activity to fields

[9] See, for example, Schmookler (1966); Sokoloff (1988); and Griliches (1990).

[10] Assignees listed on patent documents are individuals or firms who purchased the ownership of the inventions before the dates when the patents were granted.

that they had not previously worked on after their relocation. (The industry classification scheme we use here is the same as Sutthiphisal, 2006)

We also obtain biographical information of these 1,158 inventors by looking them up in population census manuscripts of the U.S. decennial censuses in 1850-1880 and 1900-1930. We supplement the census records with city directories; newspaper obituaries, as well as family and local histories. The information collected gives us a sense of an inventor's characteristics such as birth date, birth place, household composition, training and occupational background, as well as allows us to draw a detailed map of his geographical movement over time and to infer when the inventor moved to the residence where he applied for his first patent.

However, though not many, common names, for example, Richard Turner, do exist in our sample. The biographical information (for example, an inventor's addresses) is thus cross-checked with the patent information from LexisNexis to ensure that the individuals that we retrieve biographical information from the censuses are indeed the inventors in our sample. In addition, common names may lead us to record more patents made by inventors over their lifetime from LexisNexis.[11] We employ the biographical information to re-examine our patent records, in order to filter out patents created by inventors who shared identical names with those in our sample. Despite all these processes, not surprisingly, there are still cases where we cannot find any biographical information about a particular inventor, or cases where we are not certain if the inventor created the patent in question. We thus drop these inventors and patents from our analysis. Nonetheless, there is no reason to believe that doing so will lead to systematic bias in the sample.

[11] Such a problem is well documented in Trajtenberg (2005).

Table 1 summarizes the inventors that we can compile their patenting career. There are 1,131 shoe and textile inventors in total, and they all together created 14,733 patents over their lifetime. Textile inventors were slightly more productive than shoe inventors regardless of the sample years. The median textile inventor received three patents over his career, while the median shoe inventor had two patents. The higher productivity of textile inventors may be due to a higher capital intensity of the textile industry. See Sutthiphisal (2006) for a brief background of the industries.

IV. Results

A. Geographic Mobility of Shoe and Textile Inventors

We begin our analysis by examining how geographically mobile our inventors were. Table 2 categorizes them by industry and cross-sectional years, and reports the movement of these inventors both before applying for their first patent in their respective fields and during their inventive career. Except shoe inventors in 1910, more than 10 percent of inventors in both fields and cross-sectional years relocated to another state between applying their first and last patents. Such geographic mobility during one's career is higher if we look at relocation across county lines: over 20 percent in both fields and cross-sectional years. Moreover, the rate of relocation was much more pronounced at the early stage of the inventors' life. Over 45 percent of shoe inventors and 50 percent of textile inventors in the 1890 and 1910 cross-sections filed their first patent in their respective fields, while residing in a state where they were not born. However, among these inventors who did move prior to their first patent in the field, very few inventors were born in Massachusetts and later moved out of the Commonwealth. Instead, more than 90% were born in a state other than Massachusetts.

Table 3 further investigates the relocation patterns of these inventors who were not born in Massachusetts. We find that their main destination was Massachusetts, the technology center of both the shoe and the textile industries. For example, there were 166 inventors who were born in a New England state other than Massachusetts. 55.8% of them ended up living in Massachusetts when they filed their first patent in the field. A large portion of inventors who were born in a Middle Atlantic state also chose Massachusetts to be their destination. Only inventors who were born in the Midwest and other U.S. regions did not pick Massachusetts as their first choice. This may be attributable to the distance between these regions and Massachusetts. However, they only accounted for a small portion of the total inventors of interest. As for foreign immigrants, only Canadians tended to go to Massachusetts. All other foreign born inventors seemed to prefer Middle Atlantic states.

Thus far, we have constructed our index of whether the inventors relocated before their first patent in their respective fields by using their birth location instead of the location where they grew up or where they started their first jobs. Doing so may, however, introduce some complication to our analysis of the impact of relocation. For example, an individual who was born in New York and immigrated to Massachusetts with his family at the age of 5 is likely to be exposed to different environments than someone who relocated into the Commonwealth at the age of 25. It therefore may be more appropriate to treat individuals who grew up in Massachusetts in the same way regardless of whether they actually were born there. Nevertheless, the statistics reported in panel A of Table 4, which examines inventors who appeared in our 1890 cross-section, suggest otherwise. Inventor relocation decision appeared to occur after they started their first jobs and at the age of 20-39 years old or later. For example, the majority of native inventors who were born in the 1830s, 1840s and 1850s, moved into where they filed for their first patent in the respective fields in their 20s and

30s.[12] The foreign born inventors exhibit similar patterns. As shown in panel B of Table 4, most of them relocated after the age of 20.

Such patterns on the timing of the relocation also hold across different occupation. We classify our inventors in the 1890 cross-section year into 3 categories based on the occupation they hold throughout their career: machinery (for example, machinists and engineers), production (for example, shoemakers for the shoe industry and textile mill workers for the textile industry), and others. The results are shown in panel C of Table 4. Individuals with occupation in machinery tended to move at a slightly younger age than inventors in any other occupational categories. However, in all categories, most relocation occurred when individuals were more than 20 years old.[13]

Before we can turn to assessing the impact of relocation and the advantages and disadvantages different locations may offer, it is necessary to examine whether an inventor had stayed at the new location sufficiently long before he applied for his first patent in the field. It may take time before the inventor could actually benefit from what the new location offered, and more importantly, the longer time he had spent at the new location, the more likely the decision to relocate was independent of his decision to carry out inventive activity. Table 5 reports lower bound estimates of the amount of time the inventors had spent at the new location (by tracing biographical records with the new location as far back as possible in time). The evidence suggests that the majority of our inventors had spent significant amount

[12] Native inventors who were born in the 1860s and 1870s appeared to relocate at a younger age than the earlier birth cohorts. However, this is perhaps due to selection bias. As these 1890 inventors were selected because they received at least one shoe or textile patent in 1890, we have apparently under-sampled inventor cohorts who were born after 1860s since it takes time to become inventors.

[13] Although some inventors had a different occupation at the early stage of their adulthood than at the age of 30 or later, there were not many of these types of individuals. Also, the results in our subsequent analysis do not change if we use the occupation at his first job instead. However, there would be more inventors that we cannot retrieve information on their first job.

of time at the new location before applying for the first patent in the respective fields. More than 60% of inventions in all known occupational categories had lived at their new residence for over 5 years before they created their first patent in their fields. Moreover, more than one-third of our inventors had spent more than 10 years at the new location.

The results on the timing of relocation shows that most of our shoe and textile inventors decided to relocate, not only after they had started their first job but also sufficiently long before they chose to become an inventor in their respective fields. Such findings suggest that their relocation decision was likely independent of their ability at invention and that they had sufficient time to benefit from what the new location had to offer. As a result, any difference in patenting and assigning behavior across inventors who relocated to different locations is less likely to correlate with the relocation choice.

B. Effects on Patenting Behaviors

To examine if there existed any systematic difference in patenting behavior among our inventors because of their relocation decision (or location choices), we categorize them into six groups according to their origins (birth place) and destinations (where they filed their first patent in their respective fields). Table 6 displays patenting behavior, such as productivity and collaboration, of these six groups of inventors. Several patterns appear worth pointing out. First, Massachusetts residents, regardless of immigrants or natives, were strikingly more productive at shoe and textile inventions than any other group. For example, among inventors who appeared in our 1890 shoe cross-section (panel A), those who were not born in Massachusetts but later chose to relocate there, were the most successful at making shoe inventions, followed by Massachusetts natives. The median Massachusetts native made four shoe inventions and the median Massachusetts immigrant received five. In

stark contrast, the median inventor in any other category generated no more than two shoe patents over the course of his life.

Despite the strong pattern in productivity, Table 6 shows that patterns among different groups of inventors in terms of other patenting behavior are neither obvious nor consistent. Inventors who moved into Massachusetts seemed to create their first patent in the shoe or textile field earlier (at a younger age) than inventors who did move out of their birth states but did not relocate to Massachusetts. Such an advantage was not very significant, nonetheless. As for the rate of collaboration with fellow inventors, inventors who moved but not into Massachusetts, on average, had more patents that were co-invented than inventors who relocated to Massachusetts in general, though this pattern was not true for shoe inventors from the 1890 cross-section.

The results on different groups of inventors whether they switched fields of invention or extended their spectrum of invention are inconsistent as well. Only a small portion of our inventors started out in fields other than shoes and textiles. For example, in the 1890 shoe cross section, among inventors who later moved into Massachusetts, only 17.8% started their inventive career in other fields and an overwhelming majority directly began as shoe inventors. Such a finding seems to suggest that inventors in general did not switch fields to shoes and textiles. However, an assessment of their spectrum of invention over their entire inventive career indicates that shoe and textile inventors did extend their fields of invention.

The lack of consistency in patenting behavior among different groups of inventors, as reported in Table 6, seems to suggest that knowledge spillovers play a limited role in changing patenting behaviors of inventors who relocate into the technology center. If

inventors are motivated to relocate for a better access to knowledge spillovers, we should observe that inventors who move into the technology center (and thereby enjoy better access to scientific and technological ideas relevant to shoe and textile inventions) create their first patent in the field earlier, have more collaboration in making inventions in their respective field, and crossover into shoe or textile inventions from other fields, than inventors who move elsewhere. However, the findings are not supportive of the notion that knowledge spillovers play a critical role in attracting inventors to relocate to technology centers.

To be more rigorously in examining the impact of relocation and thereby infer what factor(s) motivate inventors to relocate, we employ regression analysis. In the regression analysis, we carry out two experiments. The first experiment focuses on inventors who originally lived somewhere else but moved later on. We split such inventors further into two groups: inventors who moved into Massachusetts (the technology center) and inventors who moved to elsewhere. Controlling for inventors' characteristics at the beginning (prior to the move), any residual impact on inventive activity, if found, is likely as a result of the advantages the technology center offers. Apparently, inventors who moved into Massachusetts form the treatment group in this experiment.

The second experiment focuses on Massachusetts residents. We also split these inventors further into two groups. One group consists of Massachusetts natives. The other group is comprised of immigrants. Controlling for inventors' characteristics, we can assess if immigrant inventors adjusted fast enough to behave like natives, that is, catching up. Inventors who moved into Massachusetts again make up the treatment group.

Although we try to control for inventor characteristics as much as possible, the underlying ability at invention may still differ across the control and treatment groups. Such

difference can potentially lead inventors to make systematical different decisions. Similar location choices can be made by inventors with similar underlying ability at invention. To further control for such a scenario, we therefore split our inventor sample into two categories by their occupation: production and machinery. Inventors who were involved in production required less skill on the job than inventors who were machinists, scientists or engineers.[14]

We first perform these experiments on inventors who held a job in production. Table 7 examines their patenting behavior. All specifications include a linear term for birth year, a set of indicators for birth place, a textile dummy (for inventors who appeared in our textile sample), a 1910 dummy (for inventors who appeared in our 1910 cross section), and three explanatory variables that characterize the upbringing of inventors. They include the birth state's shares of machinists, production workers, and population.[15] Most importantly, a dummy indicates whether the inventor in question come from the treatment group.[16]

Columns 1 and 2 gauge inventors' productivity at invention in their respective fields.[17] Thus, the dependent variable is a count of the number of patents with a zero-skewness log transformation. Inventors who moved into Massachusetts and inventors who

[14] As much as we have tried to control for the underlying differences in ability to invent among immigrants to other states and to Massachusetts, we may not be able to get rid of the self-selection problem. However, the problem should be less pronounced for inventors who were in production than those in machinery. Individuals in production were more homogeneous in terms of ability to invent.

[15] These shares are the birth state's shares during the teenage years of an inventor. For example, if the inventor was born in 1862 in Ohio, it will be Ohio's shares in 1880. Furthermore, shares of production was (i) share of shoe workers if the inventor's field was shoes, or (ii) share of textile works if the inventor's field was textiles.

[16] The results from comparing foreign born immigrants among each other and with those who "stay in MA" using birth region dummies instead of birth place covariates are similar to the findings from the U.S native inventor comparisons.

[17] Since a few inventors were much more productive than others, the number of patents is skewed to the right. Standard OLS regression is not suitable for such a case. We thus perform two alternative specifications. One is negative binomial, which we do not report. In the other specification, as shown in columns 1 and 2 in Table 7, we perform a zero-skewness log transformation on a count of the number of patents so as to estimate by OLS. The results from both alternatives are quantitatively similar.

moved to somewhere else had similar productivity, since the dummy for inventors who moved to Massachusetts yields a small coefficient (0.008) and it is not statistically significant. Among Massachusetts residents, the natives seemed to make more patents in the field over their career, but the difference in productivity is not statistically significant as shown in column 2.

Column 3 employs a duration model to examine whether inventors who moved to the technology center had any advantage at making their first patent in their respective field at a younger age.[18] The logic behind this idea is that if being at the technology center leads to a better access to the technology in question, it would reduce the time to learn about the technology and come up with new ideas. The positive estimate on the dummy for inventors who did move into Massachusetts (0.339) suggests that immigrants of the technology center tend to create their first patent earlier than immigrants of other regions. However, as shown in column 4, there does not seem to have much systematic difference between Massachusetts natives and immigrants in the timing of their first patent.

Columns 5 and 6 explore the collaboration rate – the number of patents in the field that were co-invented with fellow inventors. Inventors who moved into Massachusetts did not seem able to generate more patents in their respective field through collaboration, compared to inventors who moved to states other than Massachusetts. In contrast, Massachusetts natives appeared more likely to collaborate than immigrants.

Similar to those found in Table 6, these results reported in Table 7 show no clear indication that moving into Massachusetts had improved inventors' patenting. Such a finding

[18] We follow a semi-parametric approach proposed by Cox (1972).

suggests that for inventors who were involved in production, knowledge spillovers were not an important factor in changing their patenting behavior.

In contrast to inventors involved in production, knowledge spillovers appeared to be more important to inventors who held a job in machinery which required more advanced skill. This is not surprising since they tended to generate more sophisticated inventions, and more sophisticated invention are more likely to rely on a better access to the network of technological information. Table 8 reports the estimation results as we focus on such inventors. Inventors who moved to Massachusetts significantly produced more patents in their respective fields than inventors who moved to somewhere else (column 1). Column 3 suggests that for inventors, there was some positive effect on reducing the time to apply their first patent in the field by moving into Massachusetts. It is also evident that Massachusetts immigrants generated a much more patents through collaboration, than immigrants of other states, as Column 5 shows. Moreover, Massachusetts immigrants appeared to adjust quite well, compared to natives. The only exception is that Massachusetts natives had more patents with fellow inventors than Massachusetts immigrants, despite that they also had a significant lead in collaboration compared to inventors who moved to somewhere else.[19]

C. Effects on Assigning Behaviors

While moving to Massachusetts appeared to have some effects on inventors who held high-skilled jobs, it had a much significant impact on all inventors in terms of how they appropriated returns from their inventions. Table 9 reveals that regardless of industries and

[19] One should be cautious when interpreting the results on inventors who were in machinery as there may still be self-selection problem that individuals in machinery with higher ability were more likely to relocated to Massachusetts than elsewhere. Hence, the coefficients in Table 8 may overestimate the impact of a better access to technological information (knowledge spillovers) at the technology center.

cross sections, a much higher assignment rate for inventors who were associated with Massachusetts. For example, among shoe inventors who appeared in the 1890 cross section, those who relocated into Massachusetts had their first in-field patent assigned at the rate of 60%, followed by inventors who moved out of Massachusetts, and by Massachusetts natives. Though the order seemed to change slightly for different industries and cross-sectional years, inventors who moved to Massachusetts had a much higher rate at assigning their first patent than inventors who relocated to somewhere else. Similarly, for inventors who were associated with Massachusetts, a much larger portion of the total patents made over their career were assigned. Inventors who moved into Massachusetts also had a niche over inventors who relocated somewhere else in this regards.

Such patterns are also prevalent in the regression analysis. The models in Table 10 explore whether relocation affected assignment, while controlling for inventors' characteristics. The first four columns focus on production workers. Columns 1 and 2 examine whether the inventors in the treatment group had a higher chance of assigning their first in-field patent than those appearing in the control category. The results show that the probability of assigning the first in-field patent was significantly higher for Massachusetts immigrants than immigrants of other states. Moreover, Massachusetts natives seemed to have a better chance at assigning their first in-field patent than immigrants to Massachusetts, but the difference in productivity is not statistically significant as shown in column 2. Columns 3 and 4 explore the assigning behavior of inventors over their entire career by comparing the number of assigned patents in the field to the total number of patents in the field. Given that the estimated coefficient on the dummy for inventors who moved into Massachusetts is huge and at the verge of statistical significance (17.883), Massachusetts immigrants appeared to assign more often than immigrants of other states. Among

Massachusetts residents, immigrants also assigned more often than natives. The high rate of assignment for Massachusetts immigrants as compared to natives may arise from the fact that Massachusetts natives tended to appropriate returns from their inventions (patents) by organizing firms, instead of selling the rights to the patents to another party.

The last four columns look at inventors who held a higher-skilled job, in machinery. The results in both columns 5 and 6 show that there was little difference between the treatment and control groups in the chance of selling or licensing the rights to the first patent in the field. Such a finding may result from that machinists relocated at a younger age than individual in productions, and it may need time to establish networks at the new location so as to successfully sell their inventions. Another possible explanation is that machinery invention was likely more capital intensive, and hence may take longer time to secure assignment. This may affect the assignment rate of the first patent more significantly than the stream of patents over one's career. Column 7 seems to confirm this idea. It shows that inventors who moved to Massachusetts had a much higher portion of the total number of patents in the field sold or licensed to another party. The large estimate on the dummy for Massachusetts immigrants in column 8 seems to imply that Massachusetts immigrants assigned their patents more often than natives.[20]

V. CONCLUSION

In this paper, we seek to answer what factor(s) motivate inventors to relocate. In other words, what do different locations, particularly technology centers, offer to inventors? Two factors often suggested in the literature are examined here: knowledge spillovers and market coordination mechanisms for trade and investment in technology. Though we do not

[20] The results from comparing foreign born immigrants among each other and with those who "stay in MA" are similar to the findings from the U.S native inventor comparisons.

observe why inventors moved, based on inventors' revealed preference on location, we infer the relative importance of these two factors on inventors' location choices. We choose to explore inventors in the American shoe and textile industries in the late nineteenth century, instead of contemporary inventors for a few reasons. First, the shoe and textile industries were highly concentrated in Massachusetts in that period. Second, the historical records, such as U.S. decennial census, its manuscripts and city directory, allow us to trace inventors over the course of their life, which in fact is hardly possible for contemporary inventors. Finally and most importantly, tracing inventors in details provides a means to establish the causal link between relocation and changes in inventive activity.

We find that inventors who moved to Massachusetts had a much higher rate of selling and licensing (assigning) their patents than inventors relocated elsewhere. Even inventors who were in production (less skilled jobs) had a better chance in assigning their first patent, as well as exhibited a higher rate of selling and licensing the total number of patents made over their entire career, than those who relocated to other states. These findings suggest that market coordination mechanisms for trade and technology had an impact on inventors, regardless of high or low-skilled. On the other hand, the impact of knowledge spillovers was only visible on the group of inventors who held a high-skilled job. Inventors who moved to Massachusetts and held a high-skilled job created more patents, generated the first patent in the field at a slightly younger age, and collaborated with fellow inventors more frequently, than their counterparts who moved to elsewhere. However, such patterns were missing from inventors who were involved in production.

Some implications arise from these results. Given that a better access to technical knowledge at technology centers appears to benefit only a small set of inventors, to facilitate invention, it may be more important to devise a means of disseminating such critical

information to a broader range to inventors, so as to facilitate invention. On the other hand, as even the unlikely inventor, such as one who held a low skilled job indirectly benefit from market coordination mechanisms from by residing at the center of invention, for developing counties, which often do not enjoy a high level of human capital but have plenty less-skill workers, perhaps setting up market coordination mechanisms for trade and investment in technology or easing obstacles of accessing them may be a first step for these countries in order to transform themselves to become innovative economies.

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TABLE 1

SUMMARY OF THE SAMPLE

Field	Sample year	No. inventors	Total no. of patents made	No. of patents in the field each inventor made over career (median)
Shoes	1890	218	2064	2
	1910	259	3751	2
Textiles	1890	332	3859	3
	1910	322	5059	3

Sources and Notes: LexisNexis, "U.S. Patents"; USPTO, "Full-Page Images"; Sutthiphisal, "Geography." The reported figures are the numbers of inventors and patents that we can compile their patenting career.

TABLE 2

GEOGRAPHIC MOBILITY OF SHOE AND TEXTILE INVENTORS

		Moved during patenting career (share)		Whether moved from the birth place before the first patent in the field was filed (share)					
				Moved			Did not moved		
Field	Year	To different county	To different state	Into MA	Into other states	Out of MA	Stay in MA	Stay in other states	Unknown birth place
Shoes	1890	21.6	10.1	20.6	22.9	2.8	18.3	18.8	16.5
	1910	22.8	6.9	20.5	23.6	2.3	17.0	20.1	16.6
Textiles	1890	29.8	18.1	17.8	31.9	5.1	9.3	18.7	17.2
	1910	22.4	12.4	22.0	29.8	3.1	11.2	19.3	14.6

Sources: LexisNexis, "U.S. Patents"; USPTO, "Full-Page Images"; U.S. Decennial Census of Population Manuscripts, 1850-1880 and 1900-1930; Ancestry.com (U.S. City Directories, mostly in 1890 and Family and Local Histories); and Sutthiphisal, "Geography."

TABLE 3

ORIGINS AND DESTINATIONS OF INVENTORS WHO WERE NOT BORN IN MASSACHUSETTS AND LATER MOVED BEFORE THEIR FIRST PATENT IN THE RESPECTIVE FIELDS

		Where the first patent in the field was filed (share)				
	Total	MA	Other New England	Atlantic	Mid West	Other U.S. states
Birth region	Inventors					
Other New England	166	54.8	22.3	16.9	4.8	1.2
Atlantic	68	38.2	13.2	27.9	14.7	5.9
Mid West	36	19.4	5.6	11.1	50.0	13.9
Other U.S. states	29	13.8	6.9	13.8	13.8	51.7
Great Britain and Ireland	124	36.3	14.5	41.9	4.8	0.0
Germany	60	20.0	1.7	60.0	15.0	0.0
Canada	44	65.9	18.2	6.8	4.5	0.0
Other foreign countries	53	28.3	7.5	45.3	11.3	0.0
Industry and years	Patents					
Shoe patents in 1890	266	41.0	7.9	28.9	15.8	6.4
Textile patents in 1890	424	34.4	21.2	36.8	4.5	3.1
Shoe patents in 1910	405	57.3	4.4	16.8	13.1	8.4
Textile patents in 1910	450	41.6	13.6	32.4	5.1	7.3

Notes: The U.S. regional groupings are based on the U.S. Census Bureau and they as follows. (a) Other New England – ME, NH, VT, CT, and RI. (b) Atlantic – NY, PA, NJ, DE, DC, and MD. (c) Mid West – IL, IN, MI, OH, WI, IA, MN, and MO. (d) Other U.S. states – AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY, KS, ND, NE, SD, AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA, WV, AK and HI.

TABLE 4

ESTIMATED AGE WHEN AN INVENTOR RELOCATED TO THE STATE WHERE HE APPLIED FOR HIS FIRST PATENT IN THE FIELD

Sample year		No. of inventors	Estimated age at the time the inventor moved to the state he filed for his first patent in the field (share)						
			0-9	10-19	20-29	30-39	40-49	>= 50	Unknown
			A. U.S. born by birth cohorts						
1890	1830s	42	0.0	11.9	21.4	28.6	11.9	19.0	7.1
	1840s	47	0.0	8.5	25.5	38.3	19.1	0.0	8.5
	1850s	48	6.3	14.6	31.3	41.7	2.1	0.0	4.2
	1860s	19	5.3	26.3	52.6	10.5	0.0	0.0	5.3
	1870s	1	100.0	0.0	0.0	0.0	0.0	0.0	0.0
			B. Foreign born by birth cohorts						
1890	1830s	25	0.0	8.0	40.0	20.0	20.0	8.0	4.0
	1840s	42	4.8	9.5	19.0	47.6	14.3	0.0	4.8
	1850s	45	6.7	15.6	48.9	24.4	4.4	0.0	0.0
	1860s	11	18.2	27.3	54.5	0.0	0.0	0.0	0.0
			C. U.S. and foreign born by occupations						
1890	Machinery	123	4.1	12.2	37.4	25.2	12.2	2.4	6.5
	Production	106	5.7	14.2	32.1	33.0	6.6	3.8	4.7
	Other	39	0.0	12.8	28.2	33.3	12.8	7.7	5.1
	Unknown	15	6.7	13.3	6.7	60.0	6.7	0.0	6.7

Notes: The estimated age is an upper bound estimate because it is the age obtained from tracing the inventor in the biographical records as far back in time as we can.

TABLE 5

ESTIMATED NUMBER OF YEARS THE INVENTOR HAD SPENT AT THE NEW RESIDENCE BEFORE APPLYING FOR HIS FIRST PATENT IN THE FIELD

Sample year	Occupation	No. of inventors	Lower bound estimate of years of residency before filing the first patent in the field (share)			
			>= 3 years	>= 5 years	>= 10 years	Unknown
1890	Machinery	123	66.7	62.6	37.4	6.5
	Production	106	67.9	62.3	36.8	4.7
	Other	39	66.7	61.5	33.3	5.1
	Unknown	15	40.0	40.0	20.0	6.7

Notes: The estimated years of residency is a lower bound estimate because it is the year obtained from tracing the inventor in the biographical records as far back in time as we can.

TABLE 6

PATENTING BEHAVIORS BY INVENTORS' DESTINATION

Destination	No. of inventors	No. of patents in the field each inventor made (median)	Age at the first patent in the field (mean)	Share of patents in the field being collaborated (mean)	Patenting in other fields: First patent was in other fields (share)	Patenting in other fields: Share of patents in other fields (mean)
A. 1890 shoe inventors						
Unknown	36	1	42	1.1	8.3	64.8
Into MA	45	5	37	9.8	17.8	33.7
Into other states	50	1.5	41	6.3	18.0	51.1
Out of MA	6	2	38	19.4	16.7	23.1
Stay in ma	40	4	33	11.5	7.5	29.5
Stay other states	41	2	38	9.5	19.5	43.0
B. 1910 shoe inventors						
Unknown	43	1	36	8.7	14.0	42.9
Into MA	53	9	39	6.4	26.4	33.9
Into other states	61	1	42	7.3	16.4	40.4
Out of MA	6	2	43	2.8	0.0	9.0
Stay in ma	44	7	37	11.5	18.2	22.6
Stay other states	52	1	39	5.2	13.5	47.9
C. 1890 textile inventors						
Unknown	57	2	45	14.7	7.0	45.0
Into MA	59	7	36	11.7	20.3	33.1
Into other states	106	3	38	13.8	16.0	40.7
Out of MA	17	3	39	15.0	35.3	27.1
Stay in ma	31	4	38	23.3	16.1	32.4
Stay other states	62	3	37	15.7	16.1	40.1
D. 1910 textile inventors						
Unknown	47	2	38	15.8	12.8	48.2
Into MA	71	6	37	7.9	5.6	19.4
Into other states	96	3	40	14.5	11.5	36.2
Out of MA	10	1.5	38	3.3	0.0	25.0
Stay in ma	36	7	38	13.7	8.3	29.8
Stay other states	62	3	34	18.0	8.1	24.3

Notes: A patent is classified as being collaborated if there were more than one patentee for that patent.

TABLE 7

PATENTING BEHAVIOR REGRESSIONS OF NATIVE INVENTORS WHO WERE IN PRODUCTION OF THE RESPECTIVE FIELDS

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of patents in the field		Age at the first patent in the field		Share of patents in the fied being collaborated	
Constant	12.147	28.208			-196.686	-661.650
	(0.59)	(1.18)			(0.35)	(1.11)
Birth year	-0.006	-0.015	0.215	0.181	0.135	0.394
	(0.55)	(1.15)	(7.99)**	(7.77)**	(0.45)	(1.26)
Textile dummy	0.241	-0.256	0.086	-0.298	3.497	3.811
	(0.83)	(1.12)	(0.31)	(1.30)	(0.45)	(0.67)
Year 1910 dummy	0.368	0.397	-4.101	-3.599	0.959	-1.548
	(1.23)	(1.57)	(7.40)**	(7.92)**	(0.12)	(0.25)
Share of population in the birth state	-0.133	-0.193	-0.030	-0.083	-6.998	-3.490
	(1.36)	(0.92)	(0.28)	(0.41)	(2.66)**	(0.67)
Share of machinists in the birth state	0.119	0.051	0.037	0.032	1.283	-0.655
	(2.42)*	(0.75)	(0.69)	(0.38)	(0.97)	(0.39)
Share of production in the birth state	-0.065	-0.026	-0.032	-0.024	-1.254	-1.654
	(1.46)	(0.77)	(0.71)	(0.70)	(1.04)	(1.98)
Whether moved in to MA 1	0.008		0.339		-0.687	
	(0.03)		(1.25)		(0.09)	
Whether moved in to MA 2		-0.433		-0.209		-61.940
		(0.35)		(0.16)		(2.02)*
Birth region dummies	yes	yes	yes	yes	yes	yes
Observations	81	95	81	95	81	95
R-squared	0.16	0.11			0.31	0.15

Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Notes: The number of patents in the field is zero-skewness log transformed. Whether moved into MA 1 = 1 for "into MA," and 0 for "into other states." Whether moved into MA 2 = 1 for "into MA," and 0 for "stay in MA." The birth region dummies are Atlantic, Midwest Other New England states, and Other U.S. states. See Table 3 for more details on the birth region classification.

TABLE 8

PATENTING BEHAVIOR REGRESSIONS OF NATIVE INVENTORS WHO WERE IN MACHINERY

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of patents in the field		Age at the first patent in the field		Share of patents in the fied being collaborated	
Constant	34.497	77.590			203.481	172.731
	(1.66)	(3.12)**			(0.84)	(0.53)
Birth year	-0.017	-0.040	0.088	0.076	-0.110	-0.075
	(1.57)	(3.00)**	(6.96)**	(6.45)**	(0.84)	(0.43)
Textile dummy	0.332	0.291	0.105	-0.014	4.112	2.556
	(1.12)	(1.09)	(0.47)	(0.08)	(1.19)	(0.74)
Year 1910 dummy	0.513	1.116	-1.558	-1.252	-4.520	-8.275
	(1.50)	(3.70)**	(4.94)**	(4.99)**	(1.13)	(2.11)*
Share of population in the birth state	-0.022	-0.101	0.034	0.050	-0.119	-2.932
	(0.20)	(0.65)	(0.42)	(0.42)	(0.09)	(1.44)
Share of machinists in the birth state	-0.095	-0.069	-0.058	0.001	-0.388	-0.255
	(1.59)	(0.93)	(1.31)	(0.01)	(0.56)	(0.27)
Share of production in the birth state	0.070	0.048	0.032	0.021	-1.023	-0.180
	(1.39)	(1.46)	(0.98)	(0.93)	(1.75)	(0.42)
Whether moved in to MA 1	0.792		0.129		7.754	
	(2.55)*		(0.59)		(2.15)*	
Whether moved in to MA 2		-0.204		0.466		-17.705
		(0.20)		(0.66)		(1.34)
Birth region dummies	yes	yes	yes	yes	yes	yes
Observations	112	147	112	147	112	147
R-squared	0.16	0.15			0.19	0.11

Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Notes: See Table 7.

TABLE 9

ASSIGNING BEHAVIORS BY INVENTORS' DESTINATION

Destination	No. of inventors	First patents in the field was assigned (share)	Share of patents in the field made over career were assigned (mean)
	A. 1890 shoe inventors		
Unknown	36	27.8	21.5
Into MA	45	60.0	51.2
Into other states	50	38.0	27.6
Out of MA	6	50.0	30.6
Stay in ma	40	45.0	46.7
Stay other states	41	36.6	28.6
	B. 1910 shoe inventors		
Unknown	43	25.6	22.3
Into MA	53	50.9	49.2
Into other states	61	18.0	18.5
Out of MA	6	66.7	55.6
Stay in ma	44	61.4	56.9
Stay other states	52	19.2	18.6
	C. 1890 textile inventors		
Unknown	57	35.1	35.3
Into MA	59	40.7	39.3
Into other states	106	33.0	26.4
Out of MA	17	11.8	28.2
Stay in ma	31	35.5	35.5
Stay other states	62	22.6	25.4
	D. 1910 textile inventors		
Unknown	47	44.7	32.4
Into MA	71	54.9	59.4
Into other states	96	28.1	31.0
Out of MA	10	40.0	48.4
Stay in ma	36	52.8	53.4
Stay other states	62	37.1	39.2

TABLE 10

ASSIGNING BEHAVIOR REGRESSIONS OF NATIVE INVENTORS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Inventors were in production				Inventors were in machinery			
	Whether the first patent in the field was assigned		Share of patents in the field were assigned		Whether the first patent in the field was assigned		Share of patents in the field were assigned	
Constant	-47.081	-22.351	-1348.687	-925.800	10.304	-23.609	-79.056	-1050.466
	(1.64)	(0.68)	(1.67)	(0.98)	(0.57)	(.)	(0.16)	(1.86)
Birth year	0.025	0.015	0.743	0.530	-0.006	0.016	0.050	0.592
	(1.62)	(0.88)	(1.70)	(1.06)	(0.56)	(1.43)	(0.19)	(1.96)
Textile dummy	-0.263	-0.084	-18.107	-17.262	0.320	-0.326	19.699	0.513
	(0.69)	(0.29)	(1.60)	(1.91)	(1.22)	(1.45)	(2.74)**	(0.08)
Year 1910 dummy	-0.374	-0.069	-6.382	4.921	0.123	0.046	16.709	8.764
	(0.95)	(0.21)	(0.55)	(0.49)	(0.41)	(0.18)	(2.01)*	(1.28)
Share of population in the birth state	0.094	0.489	3.698	14.499	-0.009	-0.064	-1.507	-1.438
	(0.72)	(1.82)	(0.97)	(1.74)	(0.10)	(0.45)	(0.57)	(0.40)
Share of machinists in the birth state	-0.036	-0.141	-1.021	-3.214	0.032	-0.024	0.967	1.333
	(0.55)	(1.45)	(0.53)	(1.19)	(0.60)	(0.39)	(0.67)	(0.79)
Share of production in the birth state	-0.038	-0.016	-0.867	-0.381	-0.045	0.018	-0.720	0.466
	(0.60)	(0.35)	(0.50)	(0.29)	(1.01)	(0.66)	(0.59)	(0.62)
Whether moved in to MA 1	0.806		17.883		-0.008		12.324	
	(2.18)*		(1.69)		(0.03)		(1.64)	
Whether moved in to MA 2		-0.364		10.356		-0.373		13.501
		(0.22)		(0.21)		(0.42)		(0.59)
Birth region dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	81	95	81	95	112	146	112	147
R-squared			0.17	0.14			0.14	0.12

Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

Notes: See Table 7.