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Spillovers, absorptive capacity and agglomeration☆

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ABSTRACT

I study knowledge spillovers in an industry where firms are heterogeneous in their ability to adopt knowledge (absorptive capacity). I set up a model in which firms choose locations anticipating potential gains and losses from other firms' R&D activity. I apply the model to the US software industry and obtain the following results: the data supports localized knowledge spillovers; firms that have higher absorptive capacity are sorted into more agglomerated counties; ignoring firm heterogeneity leads to biased estimates of gains from spillovers; spillovers play an important role in explaining the geographic distribution of firms, but only within regions with high R&D activity.

1. Introduction

Knowledge spillovers lie at the heart of many economic theories. In the models of endogenous growth, cross-firm spillovers are essential in creating increasing returns to scale (Romer, 1986). In urban economics, geographically localized spillovers are used to explain why economic activity tends to be densely concentrated in space (Glaeser, 1999). In Ricardian models of international trade (Eaton and Kortum, 2001, to name just one example), the lack of perfect cross-country spillovers is instrumental in generating trade flows. In the development literature (for instance, Feenstra, 1996), localized spillovers are the source of persistent gaps in productivity across countries. In the above theories, it is crucial to know the scope of knowledge spillovers and the magnitude of their economic impact.

Quantifying knowledge spillovers is a difficult task as they are almost never directly observed. A usual approach is to correlate each firm's knowledge-generating activity to the performance of its neighbors, assuming that the former causes the latter. However, this approach may be problematic if spillovers affect firms differentially, that is, if firms are heterogeneous in *absorptive capacity*, an ability to improve when exposed to knowledge spillovers. An advanced technology firm located in a rural area may not bring any benefits to its geographic neighbors, as they are likely to produce only basic varieties of the final good and not rely on the frontier technology. The same firm located in a megapolis with hundreds of advanced competitors who are eager to find and adopt latest inventions is likely to create positive externalities. To understand how a spillover from location A affects firms at location B one has to answer two questions: What is the spillover's impact on a firm at B, given this firm's absorptive capacity? What are the absorptive capacities of firms attracted to B?

To create a framework for addressing these questions, I construct a model of location choice for firm headquarters[1] in the presence of R&D spillovers, assuming unobserved heterogeneity of firms in absorptive capacity. I demonstrate that firms in this model who are more responsive to spillovers tend to be over-represented in agglomerated locations. Then, I apply the model to data on production and locations of firm headquarters in the US software industry. I find evidence that spillovers within this industry exist and are highly localized in space. I demonstrate that the spatial sorting of firms by absorptive capacity produces substantial differences in the economic impact of spillovers across geographic locations. A researcher who ignores endogeneity of firm locations will tend to overestimate productivity gains from spillovers in remote areas and misinterpret the effect of sorting by absorptive capacity as evidence that spillovers decay with distance.

I model location choice as a static two-period entry game. There is a fixed mass of firms who simultaneously choose locations

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[1] In what follows, I use the terms "firm location" and "firm headquarter location" interchangeably.

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for their headquarters in the first period. In the second period, which can be thought of as consisting of several years, the firms produce the final good; the firms cannot relocate or exit during this time. The firms have innate differences in absorptive capacity, which they are endowed with at the time of birth. Firms invest into their R&D stocks, which in turn generate spillovers. Spillovers decay with distance, consistent with a large literature including Greenstone et al. (2010); Jaffe et al. (1993); Lychagin et al. (2016), to name just a few examples. Locations differ exogenously in the costs of inputs. Firm-specific costs are also affected by spillovers and own R&D.

In equilibrium, the location choice and hence the spatial distribution of firm headquarters is shaped by three forces. First, there is an agglomeration force induced by spillovers. Spillovers between any pair of firms decay with distance; by locating closer to each other, firms may enjoy higher productivity gains from spillovers. Since firms vary in absorptive capacity, they respond differentially to this force: a firm who benefits more from spillovers is drawn more strongly to agglomerated regions, even if these regions are expensive and expose the firm to tough competition. Second, locations vary in the level of exogenous natural advantages that affect firm profits irrespective of other firms' locations. Finally, there is a dispersion force caused by idiosyncratic location preferences of firm owners and managers.[2]

Since the force induced by spillovers acts differentially on firms, it creates sorting. Identification of the model's main parameters relies on detecting the magnitude of this sorting pattern in the joint distribution of firm headquarter locations and absorptive capacities. While absorptive capacity is not directly observed, its distribution in the population of firms can be inferred from a firm-level panel dataset on production occurring in the second period of the game. The temporal dimension of the data permits the estimation of each firm's absorptive capacity by correlating the variation in the firm's total factor productivity to the R&D stocks of its geographic neighbors. Although these firm-level estimates are inaccurate in the short panel setting, they can be used to identify the joint density of firm absorptive capacities and locations, if the number of firms in the sample grows to infinity. This density is then fitted to the predictions of the location choice model in order to identify the model's key parameter that explains the influence of potential spillovers on the firms' location decision.

In the empirical application, I focus on the U.S. software industry. Software firms are highly agglomerated around Silicon Valley in California and Boston, Massachusetts. It is commonly believed that knowledge spillovers are partly responsible for this extreme agglomeration. There is a body of anecdotal evidence that spillovers play an important part in computer-related sectors and that they are highly localized in space (e.g., Saxenian, 1996 provides a number of supporting stories). There is also evidence that the software industry features significant firm heterogeneity in absorptive capacity (Matusik and Heely, 2005). Computer-related industries demonstrate heterogeneity at the regional level, too: major industry clusters differ in terms of firm turnover, labor mobility and attitudes towards cooperation, either due to historical accidents or differences in state laws related to non-compete agreements (Fallick et al., 2006; Saxenian, 1996).

The aim of my empirical application is twofold: first, to determine how the impact and the geographic scope of spillovers are affected by the firm heterogeneity, and second, to quantify an overall agglomeration force induced by R&D spillovers. To put it in simple terms, I would like to find (1) how quickly spillovers decline with distance, (2) whether industry productivity is magnified by spillovers more strongly in high-R&D regions, (3) whether the spatial distribution of firms would be very different in the absence of spillovers.

The estimation results suggest that spillovers in the software industry are spatially localized: if the receiving firm's absorptive capacity is kept fixed, the spillover's productivity effect declines by half at a distance of 59 km from the spillover's origin. This estimate is of the same order as a typical commute distance, hinting at job hopping[3] as one possible mechanism for knowledge diffusion.[4] I also find that the pattern of spatial sorting by absorptive capacity is statistically significant. Spatial sorting visibly distorts the scope of spillovers. For instance, simulations of the model show that a spillover from San Jose, the center of Silicon Valley, has an impact in Alameda county almost two times larger than in the less populated Santa Cruz county, although both counties are approximately at the same distance from San Jose. Such difference in the effects of spillovers takes place because Alameda firms have higher absorptive capacity.[5]

My primary contribution in this paper is to provide evidence that firm heterogeneity with respect to absorptive capacity gives rise to geographic sorting on this characteristic and affects estimates of the spatial decay of R&D spillover effects. The second contribution is to provide new estimates of the rate at which the spillovers attenuate. The third one is to develop a new methodology to estimate the attenuation rate of R&D spillovers and the role these spillovers play in firm location decisions.

By modeling knowledge spillovers and location choice in one setting, this paper brings together the literature on knowledge production function, which finds its roots in the work of Zvi Griliches, and the literature on firm location decisions. This paper also contributes to the emerging discussion in urban economics and economic geography of the consequences of the firm- and individual-level heterogeneity on the spatial distribution of economic activity. Finally, my empirical approach is not only applicable in the context of knowledge spillovers. It can be used to identify any other ag-

[2] In the Appendix, I also present a version of the model that includes a centrifugal force induced by crowding in the final goods market. This force is endogenous; it depends on the equilibrium distribution of firms in space.

[3] This observation may also raise a concern that what I interpret as the effect of R&D spillovers comes from labor market pooling, a mechanism that makes thick labor markets more attractive for both employers and workers by offering better chances of a good match. As will be evident in Section 3, in order for my identification strategy to fail in this manner, the effects of labor pooling on firm sales have to be in co-movement with local stocks of software R&D. Any possible cross-sectional correlation between the two would be absorbed by the firm fixed effects in the firm sales equation. I run a sensitivity check in Section 5.2, in which I use local employment in the software industry to proxy for market thickness. As I report in Table 4, the estimate of the half-life distance does not change significantly compared to the baseline result. Although the above proxy is far from perfect (e.g., it does not control for local labor's quality, which may increase as a result of earlier R&D), this robustness check lends some credibility to my interpretation.

Another interpretational issue is whether knowledge generated via R&D diffuses freely and gives rise to positive externalities, or if the costs and benefits of knowledge diffusion are partly internalized. For instance, if knowledge travels from firm to firm via worker mobility, young workers may be offered low wages in return for access to knowledge generated by the employer. At the same time, experienced workers may be paid higher wages, as they possess knowledge accumulated at their previous jobs. Knowledge may be partly embodied in workers; a firm who loses an skilled worker may not be able to retain this worker's knowledge. The model set up in Fallick et al. (2006) would fit the above description if firm R&D expenditures were used to endow workers with human capital.

[4] There is evidence in the literature that this mechanism is at work in other industries, too. Stoyanov and Zubanov (2012) argue that their data on Danish manufacturing firms provide support for knowledge spillovers via labor mobility. In this dataset, firms who hire workers previously employed at more productive competitors experience improvements in own productivity.

[5] Although I attribute sorting solely to spillovers, one may be concerned that other agglomeration forces are at work, too. My identification argument relies on the assumption that agglomeration and congestion forces other than those caused by R&D spillovers do not correlate with firm absorptive capacities. If, for instance, absorptive capacity correlates with the benefits that firms draw from labor market pooling, the effect of labor pooling on location choices would be wrongly attributed to spillovers.