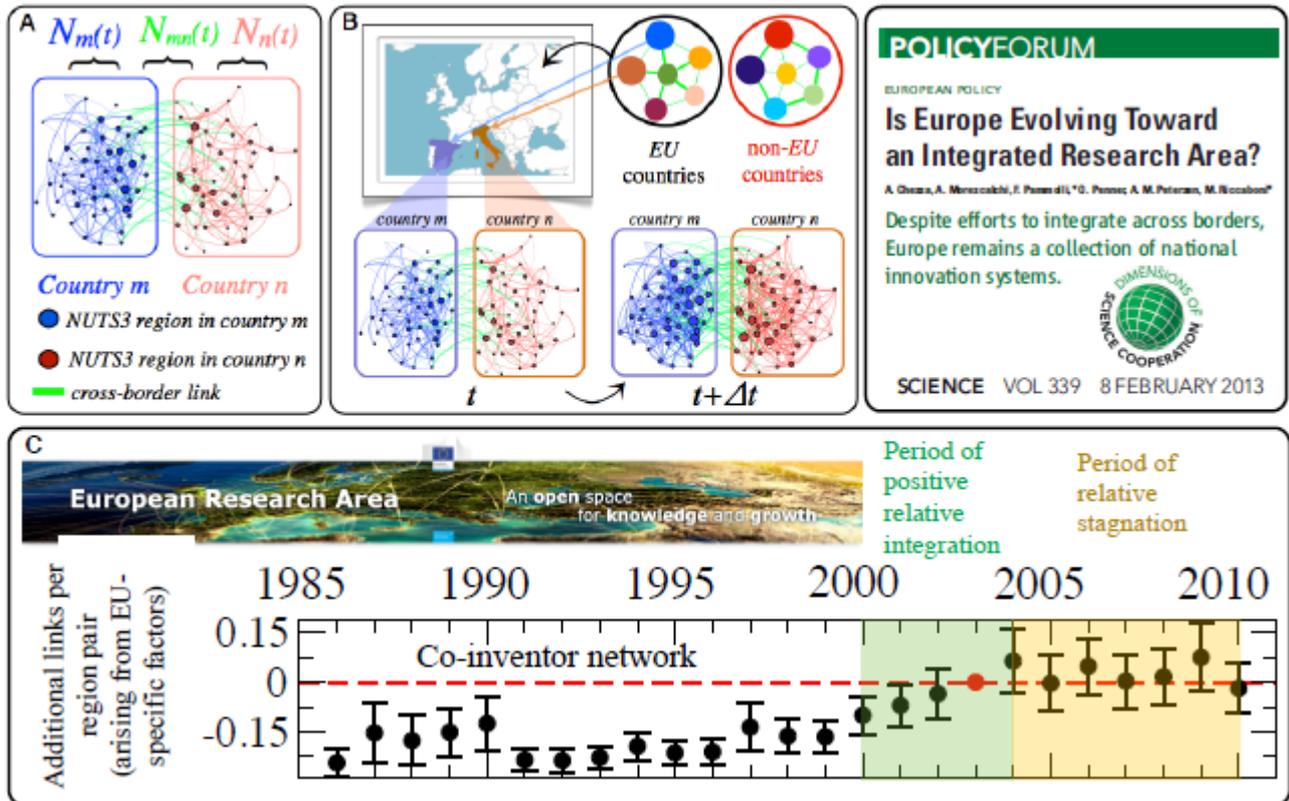# Alexander Petersen

Mobility of Inventors in the Bio-pharmaceutical Industry

Network science provides a variety of methods to better understand the complex growth trends underlying the development of the European Research Area (ERA), the EU vision to develop a homogenized innovation system that is more efficient and competitive than a collection of national innovation systems. As a collection of member states, with a rich political history, it goes without saying that the history of the EU is inextricably embedded in cultural, language, and political borders which in some cases are more or less visible. Hence, the development of an integrated European research area is a grand challenge that is a work in progress (see the European Commission report "European Research Area Progress Report 2013"). The EU aims to overcome the burden of national borders on innovation processes and knowledge transfer via directed funding that promotes transnational cooperation and transnational research infrastructures, increased mobility via harmonized labour market, and streamlined innovation policies.

To this end, in [1,2] we have performed extensive analyses of 2.4 million patents and 0.26 million publications to gain insights to the question at hand: are cross-border R&D efforts in the EU integrating faster, at the same rate, or slower than the rest of the world?

To begin to answer this question, we began by constructing 5 different regional networks by geocoding the affiliation location of each patent/publication and distinguishing the cross-region links into two types, intra-border and cross-border (see panel A). Using this methodology, we analyzed the time evolution of the intensity of these two types of links, those within country and between country, comparing the trends for EU member countries to non-EU countries.

Specifically, we analyzed the following 5 networks: (i) the patent coinventor network and (ii) the publication coauthor network which measure the intensity of interregional collaboration at the individual level; (iii) the coapplicant patent network which measures the collaboration between institutions ("applicants") located in different regions; (iv) the patent citation network which indirectly measures scientific integration by following the flow of citations from patents in one region to patents in another; and (v) the patent mobility network which measures the mobility of inventors from one region to another by tracking their location in subsequent patents.

Our overwhelming result was that the EU has not integrated any faster than the rest of the world, despite all the directed policy efforts to incentivize the development of the ERA. This result is based on the novel transdisciplinary application of econometric "treatment effect" methods to each of the 5 networks, resulting in a measure for the number of additional links in the network due to EU-specific factors.

Panel C demonstrates the trend for the co-inventor network, which shows a small period of positive relative integration (with respect to the rest of the world) from 2000-2004. However, since 2005, this trend has stabilized, despite continuing efforts to promote ERA integration. This evidence for "stagnation", which is consistent across all 5 networks, calls for policy makers to reconsider the methods, incentives, and goals for the development of the ERA.

The community structure of research collaborations can provide insight into the structural capacity, as well as the structural holes, within innovation systems, and lead to a better understanding of how EU policies can be tailored to promote the goals outlined in the recent 2013 ERA Progress report, such as defragmentation, efficiency, competitiveness, and transparency [3].

Patent and publication data can be used to construct a dynamic network picture in order to provide insight the interplay between the flows of knowledge and the mobility of innovators across space and time [1,2,4]. Important questions are: How important are the role of hubs in the collaboration networks, and are certain regions redundant? What is the length scale associated with collaboration ties and mobility flows, how has the role of distance changed over time, and how are cross-border collaborations influenced by policy ? Are there successful patterns of networking that should be incentivized within developing innovation systems?

To this end, our research has focused on the comparative differences between the US and European collaboration and mobility networks. For example, panels A and B juxtapose the top 13 coinventor communities ranked by 2009 patent output (most central region listed in legends) [2]. The distinct differences are quite clear: the density of the communities in the EU largely follows national borders, whereas in the USA the communities are highly interspatial, highlighting the distinct collaboration length scales present in each system [3].

Indeed, recent analysis of mobility networks within the pharmaceutical industry shown in panels C and D indicate the strong role played by language in Europe. Because an open, transparent, and merit-based labor market is a crucial component of the ERA development [1,4,5], features such as language, but also national and regional level policy, must be adjusted in order to achieve the goals. Panel D for the US States and Canadian provinces shows mobility networks that are not geographically correlated, and hence reflect the "best-with-best" matching that is characteristic of efficient R&D markets [6].
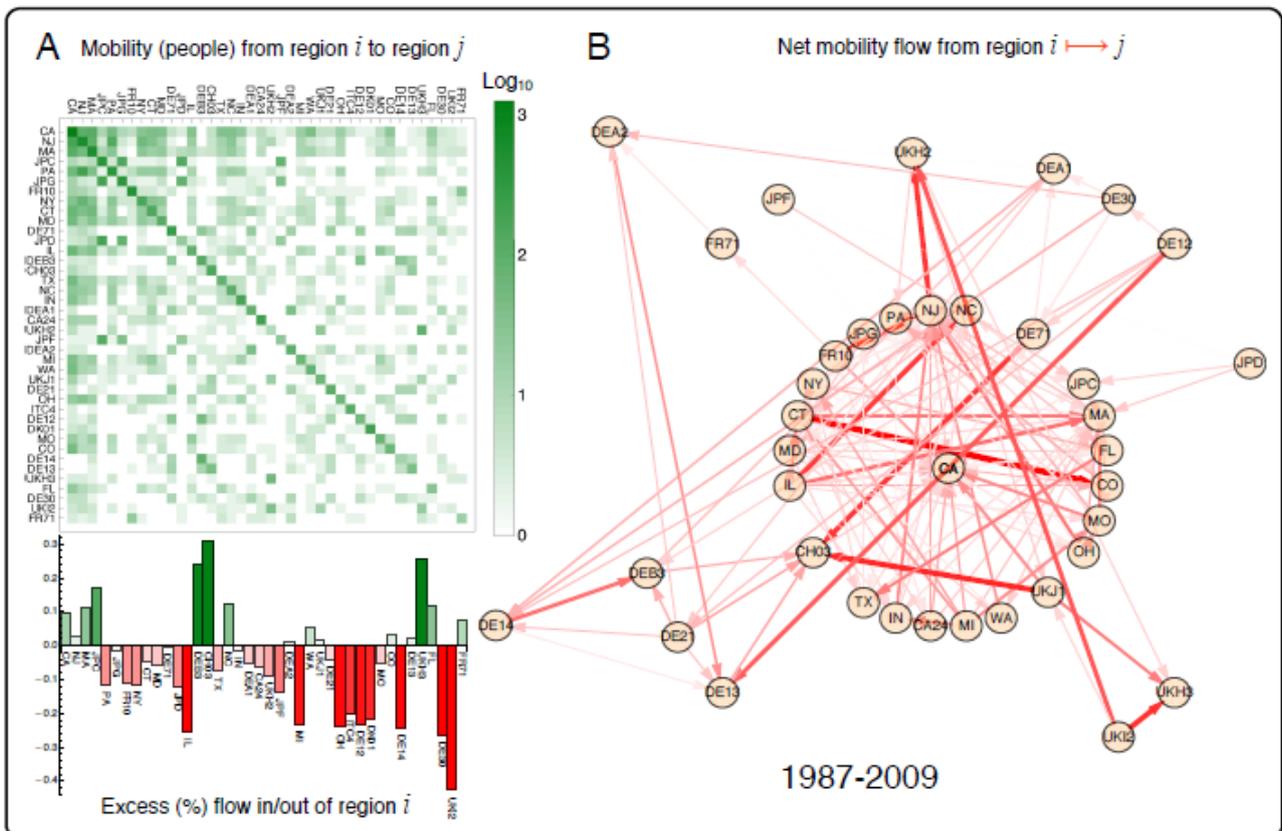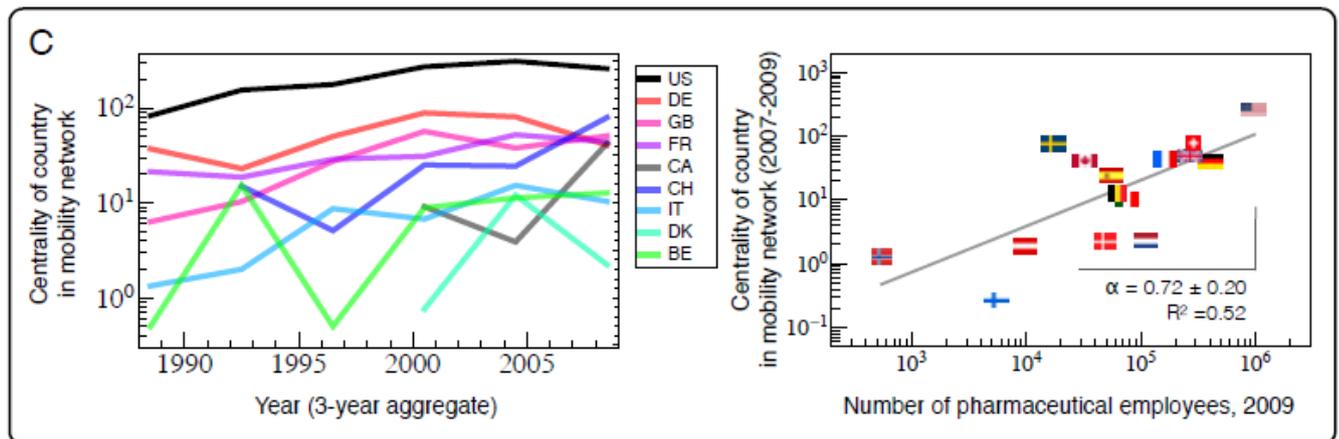
Brain drain is a problem for many developing nations who are losing valuable innovators, along with their initial training investment, to the external market. While the incentives for individuals to train/work in a new region/country are many, it is unclear at what point this becomes a problem. Despite recent advances [5], even at the most basic level, there lacks a solid understanding of the systemic effect of high-skilled laborer mobility, and whether there is a negative/positive long-term impact, and whether this impact is confined locally or extends globally.

Network science provides methods to quantify the complex flows of human labor capital across space and time. Focusing on pharmaceutical patents, we are able to track roughly 20,000 inventor transitions over the period 1987-2009 at the country and NUTS2 regional level [7]. While much of the flow is contained within NUTS2 regional borders, a considerable flow can also be seen to exist across regions and even across national borders (see panel A). The net flow into and out of regions is an initial indicator of not only the centrality of the region, but also its competitiveness within the industry. California (CA), and recently also Switzerland (specifically Basel-Stadt) have emerged as the international hubs for high-skilled labor mobility in the pharmaceutical industry, each demonstrating a large net and relative (percent) flow of people into the respective regions from a wide variety of external, yet intra-continental, sources (see panel B).

Furthermore, analyzing the trends in competitiveness over time, panel C shows the evolution of national centrality, demonstrating a recent emergence of Switzerland and Canada. Our analysis also indicates that there is a decreasing marginal returns in competitiveness to industry size, as indicated by the sub-linear scaling parameter between centrality and number of pharmaceutical employees circa 2009. This result has ramifications for the smart-specialization policies that the EU is implementing in the course of increasing the global competitiveness of the EU by the efficient allocation of Horizon2020 funds and transnational 'research buddy' plans which twin partnering regions around specific R&D efforts.

At face value, the flow of high-skilled scientists seems to be a zero-sum problem, with some countries (regions) losing and others gaining at their expense. However, it is not well-understood what is the return probability of scientists who leave their country, which leaves an open problem that requires further investigation. Indeed, there is recent evidence that the return path that knowledge spillovers can take, flowing out and and eventually back into the country of origin, provide a significant source of valuable spillover [8].

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