Attracting and Allocating an Innovation Workforce: Trade-offs and Teamwork

Jeff Alstott

Policymakers can increase the development of technology by managing their country's R&D workforce: their inventors. Policies to develop a target domain (e.g. "solar energy") frequently fund the training of new scientists and engineers to eventually work in that domain and invent new inventions. However, individuals' productivity follows a heavy-tailed distribution; most new invention is created by only a few inventors (85% of patents are authored by 30% of inventors). Policymakers can potentially improve a target domains' workforce by encouraging top inventors from outside domains to move into the target domain. We previously examined how inventors move across technological domains, using data from 4 million patents and 2.8 million inventors. Most inventors (71%) who patent repeatedly are "explorers," authoring patents in multiple domains. When explorers began patenting in a new domain they patented 15% more than an average new inventor who started their career in the same domain. Thus, recruiting explorer can yield more patents than training a new inventor in a target domain. But where can explorers be recruited from? We predicted explorers' paths between domains by creating a network map of 629 technology domains and how strongly they relate to each other[1]. Explorers follow the map: an inventor who has previously patented in a domain like "Shaping Plastics" is over 240 times more likely to successfully patent in a very related domain, like "Shaping Clay," over an unrelated domain like "Pleating Textiles". The map also predicted performance: inventors who entered domains related to their previous work patented 20% more in the new domain than inventors who moved to unrelated domains.

Policymakers seeking to increase patents in a technology domain can use the network map to identify their target domain's neighbors. The neighboring domains are good targets for recruiting high-productivity inventors. The network can thus answer a question of workforce attraction: "Where can we get the people from?" The network can also be used to address the reverse question, of workforce allocation: "Where should we send the people to?" Both governments and firms often have an existing workforce of inventors with existing expertise. However, the government's or firms's strategy may call for diversifying its technology portfolio, or even exiting its current domains altogether. Instead of hiring or training a new workforce, it may be possible to repurpose or nudge the existing workforce to work in new domains. Administrators of an existing R&D workforce can use the map to visualize where their inventors' skills are, and then identify adjacent domains where their inventors may also be productive.

This research has yielded potentially important and useful knowledge for innovation policy and workforce management. However, our understanding inventors' movements across technology domains is still far from complete. Funding from the NBER PIE Program will be used to address two important, additional questions:

1. Do technology domains reap a benefit when their inventors explore elsewhere, or is inventor movement a zero-sum game that necessitates weighing trade-offs?

2. Are inventors' explorations into new domains mediated by forming teams with local inventors?

Trade-offs: Is innovator exploration zero-sum?

It is rare that an inventor "emigrates" from one domain to another, leaving their old domain behind and exclusively inventing in the new domain. It is more common that an exploring inventor begins inventing in a new domain while continuing to invent in their old domain. Thus, the inventor builds up a portfolio of domains that they invent in. However, not all domains in the portfolio need receive equal attention. When an inventor begins patenting in new domains, what is their productivity in their old domains? It could be that adding new domains to an inventive portfolio creates synergies, and so the inventor becomes more productive in their older domains. Or it could be that the inventor has a limited capacity for invention, and

[1]There are numerous ways to use patent data to measure how related are two technology domains (using citations, co-classification, etc.). However, we developed new methods that show the disparate measurements of relatedness largely agree, if measured as the deviation from the random expectation.

working in a new domain substitutes for working in the older domains. This research project will study if and how inventors' exploration across technology domains leads to trade-offs in those domains' growth.

For those determining the R&D policy of governments or firms, whether inventor exploration is a zero-sum game can dramatically alter strategy. If exploration is not zero-sum, then policymakers may want to broadly encourage exploring other domains. If exploration is zero-sum, then trade-offs must be made: encouraging inventors to explore will diminish invention in their old domains. This is not necessarily a problem; the policymaker may determine that the older domains are not a good investment and should be exited. But we should learn if nudging inventors to new domains comes at a cost, and quantify what that cost is likely to be.

Teamwork: How do explorers interact with the locals?

Explorers have collaborators, and those collaborations have ramifications. For example, we have shown that an explorer is more likely to move to a domain X if one of their previous collaborators had patented in X before they worked together. But what about explorers' collaborations in the new domain? Can explorers enter new domains on their own, or does having a team of collaborators help? Do those collaborators need to be locals, who started their careers in the domain? It is possible that each inventor is actually permanently rooted in a specific domain, and they only appear to "move" to a different domain by forming a team with a local inventor rooted there. Perhaps inventors can indeed invent independently in a new domain, but they need local collaborators to get them started. This research project will study if and how explorers form teams as they move across domains. It will also study if teamwork affects explorers' productivity in their new or old domains, which could mediate the impact of trade-offs in innovation policy.

For those making R&D policy, whether and how teamwork affects inventors' flexibility should inform strategy. If an explorer can enter a new domain without collaborating with local inventors, policymakers can encourage exploration by encouraging just the explorer alone. But if explorers can only effectively move to new domains if there are locals to help them, then policymakers must coordinate explorers and locals to form collaborations. Building such teams would likely be costly, but it may be worth trouble if teamwork leads to increased productivity for multiple domains.

Purpose of Funding

I am a junior scholar in economics; I have not attended economics conferences and have only a few economist collaborators. This research project will be more successful if I can leverage more of what the economics field already knows about innovation workforce management, and if I can communicate new findings in outlets that economists follow. As such, this funding will be used to build connections with the economics field, primarily through attending and presenting at economics conferences. I am currently based in Singapore, so attending conferences in the US or Europe is costly, but this grant will be able to support attending several conferences.

The other major expense of this project will be computational power. In our research we have persistently sought not to analyze a sub-sample of the available data (e.g. all semiconductor patents from 1990), but instead to analyze all patents and all inventors that have a digital record. This strategy has given us more expansive results and findings that are relevant to multiple interest groups across industries and countries. However, big data requires big computation, and big computation requires data center fees. The price of data center time has gone down, which makes our research feasible, but the costs are still not negligible. This grant will help support the cost of renting data center time, so that we can continue our big data strategy.

References

1. J. Alstott, G. Triulzi, B. Yan, J. Luo, Mapping Technology Space by Normalizing Technology Relatedness Networks. *In press at Scientometrics, arXiv: 1509.07285* (2016).
2. J. Alstott, G. Triulzi, B. Yan, J. Luo, Predicting Inventors' Movements Across Technology Domains. *In submission* (2016).

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EDUCATION

UNIVERSITY OF CAMBRIDGE
PhD, Complex Systems
2014 | Cambridge, UK
Thesis: "The Behavior and Utility of Branching Processes on Complex Networks"
Examiners: Sebastian Ahnert and Ginestra Bianconi

INDIANA UNIVERSITY
MBA, Entrepreneurship and Corporate Innovation
2010 | Bloomington, IN
Won annual class case competition
Exchange study in Brazil at Fundação Getulio Vargas
GPA: 3.88

BS Biology (Honors)
BS Cognitive Science
BA History
2008 | Bloomington, IN
minors: Comp Sci, Chem, Psych
Honors Thesis in Animal Behavior
Exchange study in Australia at Australian National University
GPA: 3.96

LINKS

Github:// **jeffalstott**
LinkedIn:// **jeffalstott**
GoogleScholar://**Jeff Alstott**

COURSEWORK

Complex Systems Summer School

Adv. Scientific Programming in Python

Summer Course in Mining and Modeling of Neuroscience Data

Adv. Course in Computational Neuroscience

SKILLS

PROGRAMMING
Over 5000 lines:
Python • Matlab • R • LaTeX
Over 1000 lines:
C • Java • Scheme • Shell
Familiar:
SQL

RESEARCH

MIT MEDIA LAB & SUTD | SUTD-MIT Research Fellow
2014 – Present | Singapore
Forecasting breakthrough technologies and the behavior of hundreds of thousands of inventors, using empirically-validated predictive models. These models rest on rigorously-developed network maps of the space of all technologies.
Supervisors: César Hidalgo and Jianxi Luo

CAMBRIDGE & NIH | Joint Graduate Researcher | 7 publications
2010 – 2014 | Cambridge, UK and Bethesda, MD
Studied the behavior and purpose of cascades of activity on complex networks, including social networks and the human brain. Analyzed complex real-world data and created computational models. Developed new statistical frameworks for complex networks and wrote popular statistical software. Worked independently and in teams of up to 9 members. Advisors: Ed Bullmore and Dietmar Plenz

INDIANA UNIVERSITY | Undergrad Researcher | 2 publications
2005-2009 | Bloomington, IN
Studied how the structure and dynamics of the brain change when damaged. Created computational models to simulate such damage, then compared to clinical data from patients with brain lesions. (2 years) Advisor: Olaf Sporns

Spearheaded a new research project on rat behavior. Independently developed, ran, and analyzed experiments leading to an undergraduate thesis (2 years), then supervised and managed a team of 4 in designing and completing experiments (1 year). Advisor: Bill Timberlake.

OTHER EXPERIENCE

UNIVERSITY OF CHICAGO | Eric & Wendy Schmidt Data Science for Social Good Fellow
June 2014 – Aug 2014 | Chicago, IL
Built a fraud detector for the World Bank, using historical data of investigations and machine learning techniques. Worked within a team of 5.

POWERLAW | Author
2012-2013
Wrote a statistics software package in Python, powerlaw, for fitting particular kinds of probability distributions. >10,000 downloads and a publication with >80 citations.

REDIGO | Co-Founder
2012-2013 | Cambridge, UK
Co-founded this startup company to develop reading acceleration software. Won £15,000 investment in the Downing College Enterprise Competition.

AWARDS

2015	Best Poster Award, Conference on Complex Systems
2015	SUTD-MIT Postdoctoral Fellowship
2010	NIH-Oxford-Cambridge Scholars Program (4-year stipend and tuition)
2008	Kelley School of Business Life Science Fellowship (MBA tuition and fees)
2008	World History Essay Prize, IU History
2008	Outstanding Contribution Award, IU Cognitive Science
2007	Outstanding Achievement Award, IU Cognitive Science
2005-08	7 undergraduate research grants totaling over $10,000
2004-08	6 undergraduate scholarships covering full tuition and living expenses

PROFESSIONAL SERVICE & TEACHING

WORKSHOP CO-ORGANIZER

Conference on Complex Systems
2015 | Tempe, Arizona
Co-organized a workshop on 'Quantitative Methods for Predicting, Explaining and Describing Technical Change'. Brought together researchers in the field of technology development to discuss how to integrate theory and data.

CO-FOUNDER, PRESIDENT

Student Organization for Cognitive Science
2006-2008 | Indiana University
Started this club to develop future cognitive scientists by connecting students with educational and research resources. Organized activities such as journal clubs, lab open houses, and discussion dinners with professors.

The club now runs the Midwest Undergraduate Cognitive Science Conference, which is in its 8th year.

TEACHING ASSISTANT

2007 | Indiana University
Wrote assignments and instructional computer simulations for a new, 21 student undergraduate cognitive science course entitled "Food for Thought: Cognitive Science of Eating."

Won IU Hutton Honors College Teaching Internship Grant to fund teaching assistantship.

Peer Reviewer
Reviewer for *PLoS Computational Biology*, *PLoS ONE*, *NeuroImage*, *Schizophrenia Bulletin*, *Frontiers in Physiology*, *The Astrophysical Journal* and *European Physical Journal B*.

OTHER INTERESTS

SALONS
Organizer of online discussion salons with participants from universities around the world

GAMES
Avid player of strategy games and organizer of gaming groups

ATHLETICS
Powerlifting, Squash, Swimming, Trail Running

PUBLICATIONS

Alstott, J*., Triulzi, G.*, Yan, B., Luo, J. (2016). Mapping Technology Space by Normalizing Technology Networks. In press at *Scientometrics*. *arXiv: 1509.07285*.

Wang, J., Madnick, S., Li, X., **Alstott, J.**, Velu, C. (2015). Effect of Media Usage Selection on Social Mobilization Speed: Facebook vs e-mail. *PLoS ONE*, 10(9): e0134811.

Alstott, J., Pajevic, S., Bullmore, E., Plenz, D. (2015). Opening Bottlenecks on Weighted Networks by Adapting to Cascading Activity. *Journal of Complex Networks*, 3 (4): 552-565.

Alstott, J., Panzarasa, P., Rubinov, M., Bullmore, E., Vertes, P. (2014). A Unifying Framework for Measuring Weighted Rich Clubs. *Scientific Reports*, 4: 7258. Citations: 7

Alstott, J., Madnick, S., Velu, C. (2014). Homophily and the Speed of Social Mobilization: The Effect of Acquired and Ascribed Traits. *PLoS ONE*, 9(4): e95140. Citations: 8

Alstott, J., Bullmore, E., Plenz, D. (2014). powerlaw: a Python package for analysis of heavy-tailed distributions. *PLoS ONE*, 9(1): e85777. Citations: 81
Software downloaded >10,000 times, highly used in the field.

Alstott, J. (2013). Will We Hit a Wall? Forecasting Bottlenecks to Whole Brain Emulation Development. *Journal of Artificial General Intelligence*, 4(3): 153-163. Citations: 1

Horwitz, B., Hwang, C., **Alstott, J.** (2013). Interpreting the Effects of Altered Brain Anatomical Connectivity on fMRI Functional Connectivity: A Role for Computational Neural Modeling. *Frontiers in Human Neuroscience*, 7:649. Citations: 9

Shriki, O., **Alstott, J.**, Carver, F., Holroyd, T., Henson, R., Smith, M. L., Coppola, R., Bullmore, E., Plenz, D. (2013). Neuronal Avalanches in the Resting MEG of the Human Brain. *The Journal of Neuroscience*, 33(16): 7079-7090. Citations: 61

Alstott, J., Breakspear, M., Hagmann, P., Cammoun, L., Sporns, O. (2009). Modeling the Impact of Lesions in the Human Brain. *PLoS Computational Biology*, 5(6). Citations: 223

Alstott, J. and Timberlake, W. (2009). Effects of Rat Sex Differences and Lighting on Locomotor Exploration of a Circular Open Field with Free-Standing Central Corners and without Peripheral Walls. *Behavioural Brain Research*, 196(2): 214-219. Citations: 26

CONFERENCE PROCEEDINGS

Song, B., Triulzi, G., **Alstott, J.**, Yan, B., and Luo, J. (2016). Overlay Patent Network for Analyzing Design Space Evolution: The Case of Hybrid Electrical Vehicles. 14th International Design Conference.

WORKING PAPERS

Alstott, J.*, Triulzi, G.*, Yan, B. Luo, J. (2016). Predicting Inventors' Movements Across Technology Domains. *In submission.*

TALKS

2016 Intl. Symposium on Science of Science, Washington, DC
2015 Conference on Complex Systems, Tempe, Arizona
2015 Effective Altruism Global, Oxford, UK
2015 NetSci, Zaragoza, Spain
2014 Imperial College, London, UK, invited talk
2014 Center for Models of Life, Copenhagen, Denmark, invited talk
2013 European Conference on Complex Systems, Barcelona, Spain
2013 NIH-Oxford-Cambridge Scholars Colloquium, Washington, DC
2012 Connect1ons Conference, Cambridge, MA
2012 NIH Graduate Student Seminar Series, Washington, DC
2009 Midwest Undergraduate Cognitive Science Conference, Bloomington, IN
2007 Tri-State Animal Learning Conference, West Lafayette, IN
2007 Center for the Integrative Study of Animal Behavior, Bloomington, IN