To: The directors, NBER Productivity, Innovation and Entrepreneurship Program
From: Ashish Arora, Fuqua School of Business, Duke University, and NBER
Date: 28 April 2016
Subject: Proposal for research grant in the areas of Innovation Policy and Entrepreneurship. *This proposal relates to the role of VC funded start-ups as producers and commercializers of scientific research. We respectfully suggest that it may be appropriate for either Innovation Policy, or Entrepreneurship.*

**Title: Scientific research and commercialization strategy: Evidence from venture-backed start-ups,** Ashish Arora, Sharon Belenzon, Duke University, and Andrea Patacconi, University of East Anglia.

**Introduction:** There is evidence that corporate spending on basic and applied research in the U.S. is declining (Mowery, 2009; NSF 2012; Arora, Belenzon and Patacconi, 2015). During this time, the contribution of venture-backed firms (henceforth, start-ups) to U.S. growth and innovation has increased (Kaplan and Lerner, 2010; Puri and Zarutsky, 2012). Popular narratives assign different roles, though not mutually exclusive, to start-ups in the innovation ecosystem. Some see start-ups as a part of the overall division of innovative labor in the economy wherein start-ups commercialize knowledge generated in labs in universities and large firms. Others treat start-ups as sources of new knowledge. Indeed, some have suggested that, while support for science in large firms may be waning, entrepreneurial ventures, typically funded by venture capital may be making up some or all of the deficit (e.g., Drake, 2014).

**Research question:** The proposed research quantitatively investigates the two roles of start-ups in the innovation ecosystem. Specifically, we shall develop new measures of

(i) the extent to which scientific advances form the basis for inventions developed by start-ups;
(ii) the sources of the relevant scientific knowledge (i.e., are the scientific advances by the start-up or its founders, by university scientists, or by corporate scientists?)

We shall further relate the use of science (or absence thereof) to commercial outcomes (such as IPO or favourable acquisition). Finally, we shall explore how these relationships vary across broad technical areas and over time.

**Data and methods:** We shall match the complete set of SDC's Venture Expert venture-backed firms over the period 1980-2007 (118,599 firms) to the Web of Science, and to patent data from the United States Patent and Trademark Office (USPTO). Following established practice in the field, we shall use patenting as a measure of inventive activity. We characterize patents based on different measures of novelty. Specifically, we shall use whether the patent classes are novel or the combination of classes is novel (e.g., Akcigit, Kerr and Nicholas, 2013) or whether the text contains novel words (Arts and Fleming, 2015). In addition, breakthrough patents are characterized by whether they are in the right tail of the citations received.

We use citations to scientific literature by a patent as a measure of the nature, vintage, and source of scientific knowledge upon which the patent draws, by linking the patent references to publications in SCOPUS. Using the institutional affiliations of the authors, we can measure whether the science is internal (produced by scientists at the start-up), or produced by researchers at other corporations, or researchers at universities. We shall also develop measures of semantic similarity between the patent and scientific publications. Using these measures, we can quantify the extent to which the novel or breakthrough patents of start-ups draw upon science, the source of the relevant science, how this varies across sectors and over time. Simply put, these measures quantitatively describe the role of start-ups in the division of innovative labor in the U.S. economy. Our prior is that start-ups

do not account for a significant share of privately-generated scientific knowledge (outside the university and non-profit sector) but perhaps do account for a larger share of scientific knowledge applied to invention.

A second empirical investigation focuses upon how commercial outcomes of start-ups are related to the nature of the inventive activity. Specifically, we shall investigate whether the time to liquidity (IPO or acquisition) is shorter for science-based (or science-performing) start-ups among all start-ups, and how this has changed over time. We do not have strong priors, although our sense is that start-ups focuses on commercializing science may be more valuable but that this advantage, if it existed at all, has eroded over time.

**Contribution**

Though venture capital backed start-ups are thought to have an important part in the innovation ecosystems, their precise role is still not clear. Do they principally create new scientific knowledge, or do they mainly commercialize scientific knowledge created in university and corporate labs? Using multiple metrics, we hope to provide the first comprehensive description of how venture-backed small firms have contributed over time to innovation, and how this varies across industry and over time. By linking commercial outcomes to whether the start-up is science-based (a user of science) and whether the start-up is a producer of science, we hope to derive additional insight into how start-ups fit into the division of innovative labor and how this role has changed over time.

**Budget:**

We respectfully request a $20,000. We have budgeted $15,500 for programming and RA support for matching non-patent references in patents to SCOPUS, disambiguating authors and author affiliation. We have budgeted $4,500 for programming support to develop measures of semantic similarity between patents and selected scientific publications.

**References and Notes**

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M. Puri, R. Zarutskie, On the life cycle dynamics of venture-capital-and non-venture-capital-financed firms. *Journal of Finance* **67**:6, 2247-2293 (2012).

# ASHISH ARORA

Fuqua School of Business
Duke University, Durham NC 27709
*Ashish.arora@duke.edu*
*919-660-7746*

3712 Albritton Dr
Durham NC 27705

## POSITIONS HELD

Rex D. Adams Professor of Business Administration, 2010--
Professor, Fuqua School, Duke University, 2009 --
Visiting Professor, Fuqua School, Duke University, 2008-2009.
H. John Heinz Professor, Heinz School, Carnegie Mellon, 2007 –2009
Professor, Heinz School, Carnegie Mellon University, June 2004 – 2009
Affiliated faculty, School of Computer Science, Carnegie Mellon University, 2001—2008
Co-Director, Software Industry Center, Carnegie Mellon University, May 2001 – June 2006.
Associate Professor, Heinz School, Carnegie Mellon University, June 1998 to June 2004
Assistant Professor, Heinz School, Carnegie Mellon University, August 1991-1998.

## OTHER ACADEMIC AFFILIATIONS

Tommy Goh visiting professor, SMU, Singapore. 2016-2018
Chandrika Tandon, visiting professor. IIM Ahmedabad. 2014
Visiting professor, Bocconi University, Milan, June, 2010.
Research Associate, Productivity Program, National Bureau of Economics Research, 2008 –
Phillip Morris Visiting Professor, Scuola Santa'Anna, Pisa, June –Aug, 2004.
Visiting Associate Professor, Dept. of Economics, Stanford University, Jan - June 2002
Visiting Scholar, Center for Economic Policy Research, Stanford University, 1994-95

## EDUCATION:

PhD, (Econ) Stanford University, January 1992.
MA (Econ) Jawaharlal Nehru University, Delhi, 1986.
BA (Econ) St. Stephen's College, Delhi University, Delhi, 1984.

## PAPERS AND PUBLICATIONS

### *Books*

From Underdogs to Tigers? The Rise and Growth of the Software Industry in Brazil, China, India, Ireland, and Israel, (edited with Alfonso Gambardella), Oxford University Press, February, 2005. (Paperback edition issued September 2006.)

Markets for Technology: The Economics of Innovation and Corporate Strategy, (with Andrea Fosfuri and Alfonso Gambardella), MIT Press, 2001. (Paperback edition issued 2004.)

Chemicals and Long Term Economic Growth, editors, Ashish Arora, Ralph Landau, and Nathan Rosenberg, John Wiley and Sons, 1998. (Paperback edition issued 2000.)

### *Journal articles*

1. The paradox of openness revisited: Collaborative Innovation and Patenting by UK Innovators. (With Suma Athreye and Can Huang). **Research Policy**. *forthcoming.*
2. The Acquisition and Commercialization of Invention in American Manufacturing: Incidence and Impact. 2016. (With Wesley M. Cohen, John P. Walsh). **Research Policy**. 45 (6), 1113–1128
3. Public support and technical advance: The role of firm size. (With Wes Cohen). 2015. **Industrial and Corporate Change**. 24 (4), 791-802.

4. Make, Buy, Organize: The interplay between R&D, external knowledge sourcing and firm structure. (With Sharon Belenzon and Luis Rios). March 2014. **Strategic Management Journal** 35 (3), 317-337.
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10. "Complementarities and technology diffusion" (with Chris Forman and Jiwoong Yoon), **Information Economics and Policy**. 2010. 22(3): 228-242.
11. "An Empirical Analysis of Software Vendors' Patch Release Behavior Impact of Vulnerability Disclosure", (with Ramayya Krishnan, Rahul Telang and Yubao Yang"). **Information Systems Review,** 2010, 21(1).
12. "Competition and Patching of Security Vulnerabilities: An Empirical Analysis", (with Chris Forman, Anand Nandkumar and Rahul Telang). **Information Economics and Policy.** 2010. 22 (2): 164-177.
13. "Is the division of labor limited by the extent of the market? Evidence from the chemical industry" (with Jiwoong Yoon and Bill Vogt), **Industrial and Corporate Change.** 2009. 18(5): 785-806. (Lead Article)
14. "A breath of fresh air: Firm types, scale, scope and selection effects in drug development" (with Fabio Pammoli, Laura Magazzini and Alfonso Gambardella), **Management Science** 2009. 55(10): 1638-1653.
15. "R&D and the patent premium", (with Marco Ceccagnoli & Wesley Cohen), **International Journal of Industrial Organization**, 2008. 26 (5): 1153-1179.
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18. "Open versus Closed firms and the Dynamics of Industry Evolution" (with Farasat Bokhari) **Journal of Industrial Economics.** 2007. 55(3) 499–527
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27. **"**Measuring the Risk-Based Value of IT Security Solutions" (with Dennis Hall, Ariel Pinto, Dwayne Ramsey and Rahul Telang), **IEEE IT Professional** 2004. 6(6): 35-42.
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2. “Licensing. “ *forthcoming*. Encyclopedia of Strategic Management**.** Palgrave.
3. “Human capital and the Indian software industry” (with Surendra Bagde) in Krishnendu Ghoshdastidar (ed). Essays in Honour of Professor Anjan Mukhejee. Oxford University Press. 2011. (Revised version of *NBER working paper, 16167.*)
4. “Implications for Energy Innovation from the chemical industry” (with Alfonso Gambardella), in Rebecca Henderson and Richard Newell (eds), Accelerating Energy Innovation: Lessons from Multiple Sectors, 2010, National Bureau of Economics Research. (earlier version *NBER wp 15676*)
5. “The market for technology” (with Alfonso Gambardella), in The Handbook of Economics of Technical Change, Bronwyn H. Hall, and Nathan Rosenberg (eds.), 2010, North-Holland, Elsevier Press, Amsterdam and Oxford.
6. “The extent of globalization of software innovation” Communications of the ACM Volume 52 , Issue 2 February 2009. (With Chris Forman and Matej Drev).
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8. “The Indian software industry and its prospects”, 2008, in Sustaining India’s Growth Miracle, Jagdish Bhagwati and Charles Calomiris (eds), Columbia Business School Press, New York City, NY 2008.
9. “Patents and the market for technology”, (with Alfonso Gambardella and Andrea Fosfuri) in Keith Maskus (ed.) 2008 Intellectual Property Rights, Growth and Trade, 123-156, Elsevier Press, Amsterdam and Oxford.
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11. “Markets for technology, intellectual property rights and development” (with Andrea Fosfuri and Alfonso Gambardella) in Keith E. Maskus and Jerome H. Reichman, eds, International Public Goods and Transfer of Technology under a Globalized Intellectual Property Regime (CUP), 2005. 321-336
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13. “Emerging issues in the new economy and globalization” (with Alfonso Gambardella), in Patrizio Bianchi and Sandrine Labory (eds.) International Handbook on Industrial Policy,Edward Elgar, Cheltenham and Northampton, 2006: 28-44.
14. “The emerging offshore software industries and the United States” in Lael Brainard and Susan Collins (eds.), Brookings Trade Forum 2005, 2006, Brookings Press, DC.
15. "A Value-Based Approach to Predicting System Properties from Design" (with Scaffides, Butler and Shaw), International Workshop on Economics-Driven Software Engineering Research, 2005, St. Louis.
16. “The Globalization of the Software Industry: Perspectives and Opportunities for Developed and Developing Countries”, (with Alfonso Gambardella), in Jaffe, A., Lerner, J., and Stern, S., (eds.) Innovation Policy and the Economy, Vol 5, MIT Press, 2005. (revised version of NBER WP 10538).
17. “In the footsteps of the Silicon Valley? Indian and Irish software in the international division of labor”, (with Alfonso Gambardella and Salvatore Torrisi), in Building High-Tech Clusters, Tim Bresnahan and Alfonso Gambardella (eds), Cambridge University Press, 2004.
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19. “Research tool licensing and patenting and biomedical innovation” 2003, (with John Walsh and Wesley Cohen), in Wesley Cohen and Steve Merril (eds), Patents in the Knowledge Based Economy, NAS Press, Washington DC.
20. “Synthetic Fibers Industry”, 2003, in The Oxford Encyclopedia of Economic History, Joel Mokyr (ed) (with Ralph Landau).
21. “Chemicals”, (with Ralph Landau) in William Lazonick (Ed.) IEBM Handbook of Economics, 2002, Thompson Business Press, London.
22. “Introduction” in Measuring the payoff from chemical research , Council on Chemical Research, 2001.
23. “Software development in non-member countries: The Indian case”, in OECD Information Technology Outlook, OECD, Paris, 2000.
24. “The dynamics of industry structure: The chemical industry in the US, Western Europe, and Japan in the 1980s” (with Alfonso Gambardella), in J. Lesch (ed.) The German Chemical Industry in the Twentieth Century, Dordrecht, The Netherlands: Kluwer Academic Publishers, 2000, 407-440.
25. "Dynamics of comparative advantage in the chemical industry", (with Nathan Rosenberg and Ralph Landau), in Sources of Industrial Leadership, David Mowery and Richard Nelson (eds.) Cambridge University Press, 1999.
26. “The Chemical Industry: From the 1850s until today”, (with Ralph Landau), Business Economics, vol 34, no 4, 7-14, 1999.
27. “Chemicals” (with Alfonso Gambardella) in David Mowery (ed.), U.S. Industry in 2000: Studies in Competitive Performance, National Research Council, National Academy Press, 1999.

28. "The U.S. success story: The growth of the United States chemical industry", (with Nathan Rosenberg), in Chemicals and Long Term Economic Growth, Ashish Arora, Ralph Landau, and Nathan Rosenberg (eds.), John Wiley and Sons, 1998.
29. "Evolution of industry structure in the chemical industry" (with Alfonso Gambardella), in Chemicals and Long Term Economic Growth, Ashish Arora, Ralph Landau, and Nathan Rosenberg (eds.), John Wiley and Sons, 1998.
30. "Division of Labor in Biotechnology". (With Alfonso Gambardella.), in Annetine Gelijns, and Nathan Rosenberg (eds.), Sources of Medical Technology: Universities and Industry, 1995, National Academy Press.
31. "Appropriating Rent From Innovation: A Historical Look At The Chemical Industry", in Horst Albach and Stephanie Rosenkranz (eds) Intellectual Property Rights and Global Competition, 1995, Verlag, Berlin.

Book Reviews

1. "Fundamental patent reform and returns to R&D: The case of the Indian pharmaceutical industry", (with Lee Branstetter and Chirantan Chatterjee), *forthcoming* NBER Book Volume on The Location of Biopharmaceutical Activity, Iain M. Cockburn & Matthew J. Slaughter, editors.
2. "Shaping the twentieth century: The remarkable story of the evolution of the modern chemical and pharmaceutical industries." By Alfred D. Chandler, Jr. Harvard University Press. For **Journal of Economic Literature**, 2006), 66: 266-268 Cambridge University Press
3. "The Free-Market Innovation Machine: Analyzing the Growth Miracle of Capitalism", William J. Baumol, in **Journal of Technology Transfer**, 2003 (28), 179-81.
4. "Inventing the Internet", Jane Abbate, **Journal of Economic Literature**, 38 (4): 971-972 2000
5. "Entrepreneurship, Small and Medium Sized Enterprises and the Macroeconomy", Acs et al. (eds.), **Journal of Technology Transfer,** 25:89-102, 2000.
6. "Innovation and industry evolution" by David B. Audretsch, **Journal of Economic Behavior and Organization**, 33(1), May 1997.
7. "Market Structure, corporate performance, and innovative activity", Paul Geroski, in **Journal of Economic Literature**, June, 1996 (2).
8. "Technology and the Wealth of Nations", 1992, Freeman, C., and Foray, D. (eds.), in **Finance and Development**, 1994.

Unpublished working papers and manuscripts under preparation

1. Knowledge sharing in alliances and alliance portfolios. (With Sharon Belenzon, Andrea Patacconi.).
2. Killing the Golden Goose? The Decline of Science in Corporate R&D, 1980-2007. (With Sharon Belenzon and Andrea Patacconi) **NBER Working Paper No. 20902** January, 2015.
3. Innovation, Patenting and Licensing in the UK: Evidence from the SIPU survey (With S Athreye, C Huang). March 2014.
4. "Does in-house R&D increase bargaining power in licensing: Evidence from the pharmaceutical industry", (With Fabio Pammoli, Bill Vogt and Jiwoong Yoon*). Heinz School Working Paper.*
5. "Optimal bidding in online sequential auctions: Evidence from e-Bay auctions" (with Rema Padman, Bill Vogt and Hao Xu). *Working paper,* Heinz School.
6. "Coordination and decision making in a market with uncertainty" (with V Choudhary, Karthik Kannan, Ramaya Krishnan, and Rema Padman). *Working paper,* Heinz School.
7. "Quality Certification and the Economics of Contract Software Development", (With Jai Asundi), 1999, **NBER working paper 7260**, Heinz School WP, 99-14.

**COMMISSIONED REPORTS**

"Innovation, Patenting and Licensing in the UK: Evidence from the SIPU survey". Commissioned by the UK Intellectual Property Office, London (with Suma Athrey and Can Huang). September 2013.

"Returns to patenting and the inducement to R&D". Commissioned by the UK Intellectual Property Office, London. (with Suma Athreye and Can Huang). Submitted January 2012.

"The Indian software industry" (With V S Arunachalam, Jai Asundi and Ronald Fernandes), submitted to the Sloan Foundation, June 2000.

"Evaluating the impact of NSF funding for basic research in economics", submitted to the NSF, Aug, 1996.

"Towards a National System of Industrial Modernization Services", (with Maryellen Kelley), submitted to the National Institute of Standards and Technology, 1993.

## PROFESSIONAL ACTIVITIES

### Duke Service:

1. APT committee, Duke. 2014-2016
2. Advisory Board, Center for Entrepreneurship and Innovation, Fuqua, 2009-2015
3. Participate in meetings of the Innovation Working Group, Fuqua, 2008 - 2015.
4. Ad hoc committees: Appointments Advisory; Faculty Senior Review Committee.
5. Other teaching service: Faculty advisor: Two NV1 projects; MBA independent study projects, 2015.

### Professional Service

Member, *Workshop Steering Committee on Prioritizing and Implementing Improvements to Innovation Indicators*, National Academies of Science and Engineering. Jan 2016-Sep 2016.

Department Editor, Innovation and Entrepreneurship, Management Science 2015 – to present.

Editor, Research Policy 2008 --2014

Panel Member, European Research Council SH1 Panel, 2014-2016.

Associate Editor, Industrial and Corporate Change; Management Science (Public Sector Applications; Information systems) 2006-2009.

Editorial Board, Strategic Management Journal, Information Economics and Policy, Journal of Evolutionary Economics, Journal of Management and Governance (1997-2008).

Member, *Measuring Innovation in the 21st Century Economy Advisory Committee to Secretary of Commerce*, Dec 06 – Dec 08.

Member, Project on Competitiveness and Workforce Needs of U.S. Industry, Board on Science, Technology and Economic Policy, National Academy of Sciences, March 2006 -- 2008.

Member, *Committee on Globalization of Materials Research and Development*, National Research Council, National Academy of Sciences, NMAB, Jan 2004 – Aug 2005..

Member, *Committee on Intellectual Property Rights in Genomic and Protein-Related Inventions*, National Research Council, National Academy of Sciences, STEP Board, Feb 2004 — Nov 2005.

Member, *Job Migration Task Force*, Association for Computing Machinery, August 2004—2006

Ad hoc reviewer or panel member for (last 5 years)

National Science Foundation, National Institutes of Health, Academy of Management, BPS; Italian Ministry of Education and Research, *American Economics Review, Journal of Political Economy, Nature, RAND Journal of Economics, Review of Economics and Statistics, Strategic Management Journal*

Invited presentations and talks in AY 2015-16

- *Killing the Golden Goose? The Decline of Science in Corporate R&D*. Tokyo. 3rd AIEA-NBER Conference on Innovation and Entrepreneurship. Aug 19-20.
- *The Acquisition and Commercialization of Invention in American Manufacturing*. REITI-NISTEP Policy symposium. Aug 21.
- *Killing the Golden Goose? The Decline of Science in Corporate R&D*. Haas School, Berkeley. 3 Feb.

- *Killing the Golden Goose? The Decline of Science in Corporate R&D*. Plenary talk. Org Sci Winter Conference. 5 Feb.
- *Back to the future? The evolving division of innovative labor and the changing locus of innovation in the American Economy.* Tommy Goh Lecture, SMU, Singapore, 16 March.
- *Sowing seeds or picking the fruit? Firm capabilities and the dual effects of clusters on innovation.* INSEAD, Singapore. 15 March.
- *Killing the Golden Goose? The Decline of Science in Corporate R&D*. Carnegie Mellon University. Pittsburgh, PA. 7 April.
- *Killing the Golden Goose? The Decline of Science in Corporate R&D*. Harvard University. 8 April.