Volume Title: The Rate and Direction of Inventive Activity Revisited

Volume Author/Editor: Josh Lerner and Scott Stern, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-47303-1; 978-0-226-47303-1 (cloth)

Volume URL: http://www.nber.org/books/lern11-1

Conference Date: September 30 - October 2, 2010

Publication Date: March 2012

Chapter Title: Comment on "Generality, Recombination, and Reuse"

Chapter Authors: Benjamin Jones

Chapter URL: http://www.nber.org/chapters/c12375

Chapter pages in book: (p. 656 - 661)

Freiberger, Paul, and Michael Swaine. 2000. *Fire in the Valley: The Making of the Personal Computer,* 2nd ed. New York: McGraw-Hill.
Harrigan, K. R. 2003. *Joint Ventures, Alliances, and Corporate Strategy.* Lexington: Beard Books.
Hayek, F. A. 1945. "The Use of Knowledge in Society." *American Economic Review* 35 (4): 519–30.
Jones, Benjamin. 2009. "The Burden of Knowledge and the 'Death of the Renaissance Man': Is Innovation Getting Harder?" *Review of Economic Studies* 76 (1): 283–317.
Jovanovic, B., and P. Rousseau. 2005. "General Purpose Technologies." In *Handbook of Economic Growth,* Volume 1B, edited by Philippe Aghion and Steven N. Durlauf, 1181–222. Amsterdam: Elsevier B.V.
Langlois, R. N., and P. L. Robertson. 1992. "Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries." *Research Policy* 21:297–313.
March, J. 1991. "Exploration and Exploitation in Organizational Learning." *Organization Science* 2 (1): 71–87.
Mokyr, J. 2002. *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton, NJ: Princeton University Press.
Nelson, R., and S. Winter. 1982. *An Evolutionary Theory of Economic Change.* Cambridge: Belknap Press.
Romer, P. M. 1987. "Growth Based on Increasing Returns Due to Specialization." *The American Economic Review* 77 (2): 56–62.
Rosenberg, Nathan. 1963. "Technological Change in the Machine Tool Industry, 1840–1910." *Journal of Economic History* 23 (4): 414–43.
———. 1996. "Uncertainty and Technological Change." In *The Mosaic of Economic Growth,* edited by R. Landau, R. Taylor, and G. Wright, 334–52. Stanford: Stanford University Press.
Schumpeter, J. 1939. *Business Cycles.* New York: McGraw-Hill Book Company, Inc.
Scotchmer, S. 2004. *Innovation and Incentives.* Cambridge, MA: MIT Press.
Usselman, S. 1993. "IBM and Its Imitators: Organizational Capabilities and the Emergence of the International Computer Industry." *Business and Economic History* 22:1–35.
Weitzman, M. L. 1998. "Recombinant Growth." *Quarterly Journal of Economics* 113 (2): 331–60.
West, Joel, and Michael Mace. 2007. "Entering a Mature Industry through Innovation: Apple's iPhone Strategy." DRUID 2007 Summer Conference. http://www2.druid.dk/conferences/viewpaper.php?id=1675&cf=9.
Weyl, E. Glen, and Jean Tirole. 2010. "Materialistic Genius and Market Power: Uncovering the Best Innovations." Working Paper.

Comment Benjamin Jones

This chapter has a "big think" orientation and reveals numerous insights about the innovation process. The starting point is to recognize that knowl-

Benjamin Jones is associate professor of management and strategy at the Kellogg School of Management, Northwestern University, and is on leave from the National Bureau of Economic Research.

edge required for successful innovation is distributed across many agents. These agents do not know each other, so their individual knowledge is not easily aggregated or shared. The chapter then makes a distinction between two types of knowledge that are relevant to innovation. There is technical knowledge—the actual engineering and scientific know-how to actually make something. And there is entrepreneurial knowledge—knowledge about whether there is a market for the new thing and, if there is a market for it, whether there might be other, associated markets and complementary recombinant innovations that further justify going down the initial path.

Note immediately that there are some standard innovation flavors here. There is uncertainty about the innovative possibilities. Ex ante, it is ambiguous what these innovative opportunities are, technically and in the market. There is also an emphasis on complementarity, both the interdependence of knowledge and the consequent interdependence of agents across whom the knowledge is divided up.

But the key addition of the chapter is a flavor of Hayek, asking how distributed knowledge can be brought together and emphasizing the role of the market. If someone actually delivers an innovation to the marketplace, then distributed agents see the innovation and recombine it with their own ideas. Before the innovation is delivered to the market, there is an absence of knowledge. The core idea in this chapter is that in making the thing and bringing it to the market, the information burden on everybody else is relieved. This action turns one agent's entrepreneurial knowledge—perception of a particular opportunity—into widespread knowledge, making it easier to recombine and build into additional innovations. Another theme of the chapter is that this process may be especially critical for general purpose technologies.

The following simple formalization can capture many of the main ideas in the chapter and demonstrate the generality of applications that emerge from Bresnahan's analysis. Imagine you are considering an innovation A with value $V(A)$, which can be obtained for a cost r. Furthermore, imagine there is some possibility of combining innovation A with some other innovation B, giving your initial effort some additional value $V(A, B)$. The analysis of the chapter hinges on whether you can expect, in this world of decentralized knowledge, to capture this $V(A, B)$.

Write the expected return on the innovation A as[1]

$$\{V(A) - r\} + V(A,B) * \lambda * K.$$

Let your bargaining power be measured by $\lambda \in [0,1]$, defining the share of the additional income $V(A, B)$ that you would capture. Define $K \in [0,1]$ to represent the probability that you will perceive the opportunity of $V(A,B)$.

1. This notation and setup is not quite what was used in initial drafts of the chapter, but is simple and sufficient to capture some key ideas.

The issue is thus partly one of bargaining power over future innovations, for example, due to intellectual property rights. The issue is also one of knowledge—you may not know that the recombinant possibility even exists.

The interesting case, of course, is where $V(A)$ is less than r. Then, on your own, you may choose not to produce innovation A given its expense. Yet there may be substantial value in the recombination of A and B. The challenge is either that you do not look forward to a large share of the value (λ is low) or you do not readily perceive the combination itself (K is low).

The bargaining problem suggests that you need high λ to encourage the investment in A. However, while high λ means that you can appropriate most of the market—the $V(A,B)$—it also implies that other would-be innovators become less inclined to create B, because now they cannot get much of the recombination benefit for themselves. This trade-off, and its implications, has been studied extensively by Suzanne Scotchmer.

The emphasis and novelty of this chapter surrounds the question of knowledge itself, represented by K. Even if we solve the bargaining problem, you still will not get innovation if K is low. The innovator has little or no idea what this B is. This lack of knowledge could surround technical aspects of B, market knowledge for B, and/or B's recombinant prospects with A. These possibilities may be very hard to foresee, especially when knowledge is distributed.

Returning to the Hayek theme, one (imperfect) solution to this knowledge problem is for someone to simply create B and bring it to the market. Then people see it, resolving the K problem, and now may create A. The marketplace thus helps unleash recombinant innovation.

The general purpose technology (GPT) version of this analysis is to imagine that there are lots of potential innovations that could recombine with A (the GPT),

$$\{V(A) - r\} + \sum_i V(A,B_i) * \lambda_i * K_i.$$

This setup suggests a natural story for "inversion" as the initial step for the spread of a GPT. The GPT is originally produced with a narrow application in mind. This is the case where $V(A) > r$ and the innovation goes ahead without consideration of the recombinant possibilities. For example, computers were originally developed to perform narrowly defined calculations, and government researchers created the precursor of the Internet for their own narrow purposes. There was little knowledge about the ultimate potential (the K_i were low). But having produced A, these areas started witnessing decentralized innovation. While the A people did not see the B_i—and likely were not even thinking about B_i—suddenly there are all these agents thinking about A, because now they can see it. So the decentralized B_i people dive in and innovation accelerates; if A is a general purpose technology, decentralized innovations can really take off.

The rest of my comments will depart from the general purpose technology focus of the chapter and consider some other applications of this simple framework, which can further demonstrate its use.

Consider basic research. Basic research typically shows little or no market value directly ($V(A) < r$) but may have lots of recombinant possibilities for commercial innovations (the $V(A,B_i)$ may be large). That is often how economists describe basic research and the reason it may be underprovided. The standard policy solution is subsidization: public institutions pay scientists a wage and provide research funds. In addition, we make A freely available: we set $\lambda = 0$ for producers of basic research. Thus the distributed Bs capture the full value of recombination, incentivizing their activity. This perspective provides a standard description of the "public, open science" model, which is a good description of many national innovation systems.

The additional nuance that Bresnahan's approach reveals centers on the dissemination of basic scientific knowledge. With basic science, the output is not presented as a standard good or service, demonstrating revenues, costs, and profits in the marketplace. Rather the output is a paper, a seminar, an informal chat with colleagues. How does the commercial market learn about the new idea or whether it is valuable? That is, how successfully does the "public, open science" model solve the "low K" problem? Papers and conferences are part of the solution but may be incomplete; for example, they do not convey tacit knowledge. One solution for commercial enterprises may be geographic agglomeration around universities. Private firms locate around Stanford and Berkley, MIT, and so forth, explicitly to increase their K.

In this view, the effectiveness of agglomeration will depend on the capacity of private firms to search the university for good ideas. That is, the agglomeration solution—using a local network in place of an arms-length market—is not the Hayek-like solution. Recall the starting point of the chapter—knowledge is distributed across agents. The market may solve this problem when an innovation is sold, but if direct communication is important to acquire basic science ideas (hence explaining agglomeration) then firms' acquisition of researchers' ideas depends on the researcher's willingness to engage. If the researcher's interests or incentives are defined by producing additional basic research, why exactly does the researcher take the firms' phone calls? Does the researcher want to spend hours and hours talking to private firms?

Here the issue of openness becomes more complicated. Namely, the K issues and λ issues start to interact. Can you tell the basic researcher "you have to publish your ideas for free" ($\lambda = 0$) and also say "you still need to take calls from all these commercial people who are going to make all the income from your idea"? That is not easy. So perhaps we need to think about giving some λ back to the basic researchers, which would result in higher K for others.[2] Alternatively, we can imagine that firms will simply pay researchers for their time (i.e., a consulting fee), which would also raise K. This solution might be difficult in practice, however, given the substantial compensation and costly bargaining that might be needed with each researcher, the breadth of search the firm must undertake, and the bias expansive (and thus expensive) search may impose against small firms. These are key questions for understanding possible market failures in the commercialization of university research and the ultimate returns to basic science.

One can also think about standard setting through this lens. Think of a standard as an innovative output, A. By publicly agreeing to A, the market enhances recombinant possibilities by raising K. This knowledge is not standard marketplace knowledge based on profits from a new innovation, but rather acts to reduce market uncertainty about what the standard is going to be, facilitating recombination. By providing standards for free, one also solves the λ problem and creates stronger incentives for further innovation. One may then see a role for nonprofit or government institutions in helping set standards.

A last comment regards possible market failures. Ex ante, if a bargaining problem (λ) stymies innovation, then one could integrate the firm and achieve the first best. With Bresnahan's starting point, however, the nature of knowledge distribution is such that one does not even know who to integrate with. That is the key problem: the fact that you cannot identify the recombinant possibilities ex ante means that you cannot easily solve the bargaining problem in practice—you cannot integrate your way around it. So innovation faces a serious market failure in the sense that socially profitable innovation does not occur. At the same time, it is not clear how a government realistically solves this problem directly, given that a government cannot obviously create a better information set (especially given the advantage of decentralized firms in perceiving innovative opportunities in their markets). Given the positive spillovers from the initial innovation, coupled with these fundamental information constraints, the government's role may then be limited to subsidizing innovation broadly—not just basic science, but also commercial innovation, through such policies as research and development tax credits.

In sum, this chapter points to knowledge distribution as a key feature in understanding innovation, with applications to general purpose technologies and other areas. This framework also points toward the tension between the openness that can allow recombination and the protection of one's own commercial interest that can incentivize the individual innovations themselves. In market settings, the profitability of the initial innova-

2. This consideration would suggest, for example, some value of the Bayh-Dole Act.

tion will be sufficient for some innovative activity, and the market then acts to encourage recombination. In basic research settings, the institutions of public, open science can be understood in the same framework, but the analysis suggests that these science institutions may need a further look in helping to ensure that firms and publicly-supported researchers actually engage in efficient knowledge interchange.