SCAFFOLDING INNOVATION

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ABSTRACT

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INTRODUCTION

It is hardly possible to overrate the value . . . of placing human beings in contact with persons dissimilar to themselves, and with modes of thought and action unlike those with which they are familiar. . . . Such communication has always been, and is peculiarly in the present age, one of the primary sources of progress.

John Stuart Mill

INTRODUCTION

Complex diseases—those that arise from the combined action of many genes, environmental factors, and risk-conferring behavior—such as cancer, diabetes and nervous system disorders, exert an increasingly devastating toll on the world's population.[1] For example, according to a recent Institute of Medicine Report, by 2030 nervous system disorders alone will account for 35 percent of the projected loss of global economic output from non communicable diseases.[2] Developing treatments for complex diseases is interviews with non-traditional teams—whose members belong to different research communities such as engineering, endocrinology, and oncology —I analyze when and how the architecture of knowledge distribution erects barriers to knowledge acquisition, the effect of current legal incentives on non-traditional team formation, and how policy instruments could be redesigned to bridge structural barriers to innovation.

Several studies show that teams that bring together scientists from multiple scientific and technical backgrounds generate higher social-impact inventions than both homogeneous teams and solo inventors.[6] And breakthrough innovations (those that overturn existing paradigms or open new lines of research) are more likely to result from unusual combinations of elements from different research domains.[7] Collaborations that cut across expert communities also tend to generate high spillovers—positive externalities whose value cannot be fully captured by the inventors.[8] Moreover, as my research shows, spillovers resulting from cross-community collaboration are particularly socially valuable. These types of collaboration generate new and often long-standing connections between communities that open up entire new lines of research, and lower the uncertainty for the rest of the scientific community of doing research at those new intersections.[9]

Nevertheless, conducting research in a nontraditional team, and in particular such teams, presents a series of challenges that make it very likely that this type of team research will be underproduced by the market—that is, produced below its socially optimal level. To understand why this is the case, it is helpful to review the general argument that knowledge goods will be underproduced in a market economy. Both theoretical models of innovation and empirical studies find that market competition alone will generate investment in research and development that

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[6] *, . .,* Jasjit Sigh & Lee Fleming, *L I B : M ?* 56 MGMT. SCI. 41, 48 (2010) (showing that teams whose members have diverse technical experience and external collaboration networks outperform solo inventors and homogenous teams by generating more breakthrough innovations—as measured by patent citations—with fewer poor outcomes); Michael L. Tushman, *B I* , 22 ADMIN. SCI. Q. 587 (1977); FRANCIS C. MOON, SOCIAL NETWORKS IN THE HISTORY OF INNOVATION AND INVENTION (2013); Mark Lemley, *M I* , MICH. L. REV.

[7] *, . .,* Lee Fleming et al., *C B , G C , C* , 52 Administrative Science Quarterly 443 (2007); Xiaolin Shi et al., *I B* , 4 PloS One 6547 (2009); Brian Uzzi et al., *A C I* , 342 Sci. 468 (2013).

[8] Spillovers signal that the social value of the innovation exceeds the private value. *, . .,* Mark Lemley & Brett Frischmann, , 100 COLUM. L. REV. 257, 266 (2006). When spillovers provide crucial, basic research information necessary for follow-on innovation in a number of different technical fields, researchers generally agree that these spillovers will lead to private underinvestment. Ufuk Akcigit, Douglas Hanley & Nicolas Serrano-Velarde, *B B : B , I G ,* at 4, http://doughanley.com/files/papers/ahs_basic_research.pdf ("In an economy with both types of research [basic and applied], the major underinvestment is in basic research due to its sizable spillovers.")

[9] Part .

is quite below what is socially optimal.[10] As Kenneth Arrow theorized in 1962, underproduction results from two important features of information goods: (1) inappropriability, and (2) uncertainty.[11] The appropriability problem can be summarized as follows: the process of innovation consists primarily in the creation of knowledge about how to make new goods and provide new services. Because producing this knowledge has large upfront fixed costs, innovators will only invest in research and development if they can appropriate a sufficient amount of the returns to their investment. But information goods are non-rival (use by one firm does not prevent simultaneous use by another) and non-excludable (non-paying consumers cannot easily be prevented from accessing them).[12] As a consequence, absent the ability to keep information secret, innovators cannot recoup R&D costs simply by selling their information-containing goods in the market. Rivals, who did not incur the high fixed costs of creating that knowledge, would be able to free-ride on innovators and imitate their products at a much lower cost. Knowing this inventors will fail to optimally invest in knowledge goods. Second, a crucial feature of investment in R&D is great uncertainty about the likelihood of success of any given research project. Absent some form of insurance against failure,[13] the market will tend to discriminate against high-risk, high-variance projects.[14] In addition, some types of research findings are particularly welfare-enhancing in that they drastically reduce the uncertainty of future research projects. Think, for example, of the discovery of the mechanism of human-immunodeficiency virus (HIV) infection. Understanding the nature of the HIV virus itself as a retrovirus, that is, a virus that starts as ribonucleic acid (RNA), transforms itself into deoxyribonucleic acid (DNA), and then inserts itself into the genome of the host cell, lowered the number of research avenues into HIV therapies and increased the probability of success of each one of them—thus lowering overall uncertainty. Indeed, current successful HIV therapies are still in large

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10 *, . . .,* Kenneth Arrow, "Economic Welfare and the Allocation of Resources for Invention" In: Nelson, R. (Ed.), The Rate and Direction of Inventive Activity (1962) (modeling underinvestment in knowledge goods); Stephen Martin & John T. Scott, , 29 Res. Policy 437, (2000); Hall, B. H. (1996). "The Private and Social Returns to Research and Development." In: Smith, B.L.R, Barfield, C.E. (Eds.), Technology, R&D, and the Economy, 140-83. Brookings Institution and the American Enterprise Institute, Washington, DC.; Griliches, Z. (1992).

11 Kenneth Arrow in Nelson, R. (ed.), *D I A*, Princeton University Press (1962).

12 *, . .,* Arrow, note ___, at 614 ("[T]he cost of transmitting a given body of information is frequently very low."); Joel Mokyr ___ ("Technology, like all forms of knowledge, is non-rivalrous, so that the social marginal cost of sharing it is zero."); R. Polk Wagner, *I B F : I M C ,* 103 COLUM. L. REV. 995, 998 (2003) ("The 'fencing' of information is a remarkably futile proposition . . . It turns out that information 'want to be free.').

13 Arrow, note ____, at ____.

14 Arrow, note ___, at 616 ("By the very definition of information, invention must be a risky process, in that the output (information obtained) can never be predicted perfectly from the inputs.").

part based on the knowledge that HIV is a retrovirus.[15] This type of uncertainty-reducing research will generate large spillovers—i.e. positive societal benefits that won't be fully appropriated by the inventing firm. When creating knowledge, and thus dispelling uncertainty, is costly and has high spillover effects, firms will tend to wait for competitors to make the initial investment and then use the resulting knowledge. In turn, this will lead to underinvestment in uncertainty-reducing research.

Nontraditional team research is a special case of the underproduction of knowledge goods outlined above. The appropriability problem is exacerbated in the context of nontraditional teams.[16] This is because non-traditional team research is likely to generate valuable spillovers that cannot be appropriated by any of the collaborating members. In particular, nontraditional teams, if successful, give rise to new social connections among communities that both open up entire new lines of research and lower the risk for future researchers of carrying out research at the intersection of those communities. Indeed, because much of collaborative R&D that spans technological boundaries is carried out in early stage, exploratory research, it will generate basic knowledge regarding the feasibility and productivity of research at the intersection of multiple fields—precisely the type of uncertainty-reducing basic research described above that is likely to be underproduced by the market.[17] Finally, nontraditional team assembly entails large set-up costs and upfront risks. Bringing teams together across technical boundaries requires breaking down both social and economic barriers to collaboration, and it almost always involves both overcoming communication barriers arising from different ways of conceptualizing a problem in participating communities and overcoming entrenched practice styles (or ways of prioritizing, organizing, and carrying out work).[18] Moreover, the results of nontraditional team research are likely less predictable from those that will emerge from a homogenous team working in a well-defined research area.[19] The point here is not that team science that crosses technological boundaries will not happen—it undoubtedly does. My argument is that it will

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[15] The main line of defense against HIV infection is therapies that inhibit the functioning of the proteins that convert RNA into DNA (reverse-transcriptase inhibitors). *, . .,* Eric J. Arts & Daria J. Hazuda, *HI -1 A D* , 2 COLD SPRING HARB. PERSPECT. MED. 1, 6 (2012) (noting that the twelve therapies that target HIV reverse transcription "account for nearly half of all approved antiretroviral drugs").

[16] Appropriability concerns are heightened for any collaborative effort. *, . .,* K. Laursen & A.J. Salter, *: A ,* , RES. POL. 867, 876 (2014) (finding that "an overly strong emphasis on appropriability may be associated with reduced efforts to draw in knowledge from many different external actors in formal collaborations for innovation.").

[17] Robert D. Atkinson, *E &E ,* , 32 J. TECHNOL TRANSFER 617, 626 (2007) (explaining that "most collaborative research, whether in partnership with a university, national laboratory, or industry consortium, is more basic and exploratory than research typically conducted by a single company.").

[18] Part ___ (reporting on original empirical research on team formation). *,* Laura G. Pedraza-Fariña, *L I* , 2013 WISC. L. REV. (2013).

[19] Part ___.

happen at a level that is significantly below what is socially optimal. In many ways, nontraditional team assembly is the poster-child for governmental intervention in the market for innovation.

Yet, and despite a strong case for incentivizing nontraditional team formation, current innovation policies exacerbate rather than correct this underproduction problem. Patents, the standard argument goes, prevent free riding by copyists who did not invest in research and development.[20] But, as Amy Kapczinsky and Talha Syed have pointed out, there are some types of inventions whose social benefits are particularly hard to appropriate, even with patent protection.[21] Thus, patents "fix" the appropriability problem for some inventions, but not for others—there is as Kapczisnky and Syed note a "continuum of excludability."[22] This, in turn, distorts incentives for companies to invest in those innovations whose social benefits are easily appropriable through patent law. The continuum of excludability represents a particular problem for nontraditional team assembly. The type of spillovers generated by boundary spanning team research—forging links between different research communities reducing the uncertainty of future projects among those communities—are hard to appropriate even if a patent results from the initial investment.[23] Andrew Abbott recognized this potential distortion when he suggested a likely bias against major inventions because an inventor is likely to obtain "the entire realized social benefit of moderately cost reducing inventions but not of more radical inventions."[24] Many team research projects will also lead to joint patenting, a mode of ownership that is disfavored in the industry as generating additional coordination costs.[25] In

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20 , . ., To Promote Innovation: The Proper Balance of Competition and Patent Law and Policy, Federal Trade Commission at 48; Joel Mokyr (describing the free-riding/appropriability dilemma as leading "to a debate that is now a quarter of millennium old on how best to establish optimal incentives in technological progress."); Mark A. Lemley, Property, Intellectual Property, and Free Riding, 83 TEX. L. REV. 1031, 1073 (2005); Brett M. Frischmann, The Pull of Patents, 77 FORDHAM L. REV. 2143, 2156 (2009); Brett M. Frischmann, *A E I C M* , 89 MINN. L. REV. 917, 948–49 (2005) (pointing out that innovation scholars have focused almost exclusively on the market failures caused by free-riding but have neglected to consider the importance of providing infrastructure resources, which will often be under-supplied by the market).

21 Amy Kapczynski & Talha Syed, *C E L* , YALE L. J. (2013)

22 Kapczynski & Syed, note ___, at ___.

23 FRISCHMANN, INFRASTRUCTURE: THE SOCIAL VALUE OF SHARED RESOURCES (2012)

24 Arrow, note ____, at ____.

25 Hagedoorn, J., 2003. *,* Industrial and Corporate Change 12, 1035, 1039 ("many legal experts regard the joint ownership of intellectual property rights, such as patents, as fraught with problems, and therefore as a last resort if other arrangements have failed."); Belderbos, R., Faems, D., Leten, B., & Van Looy, B., *A I F F : E E F* , 27 Journal of Product Innovation Management 869 (2010) (finding that while inter-firm collaboration leading to joint patenting improves a firm's technological performance it has an overall negative effect on a firm's financial performance, and hypothesizing that this negative effect is due to high coordination costs); Kristie Briggs & Mary Wade, *M :* , 46 APPLIED ECON., 4370, (2014) (finding that patents held

addition, when faced with a choice of research projects, firms are more likely to choose other low-hanging fruit within their area of expertise, if that low-hanging fruit is patentable and profitable: witness the large number of patented statin drugs in the U.S. market, but the dearth of new drugs for neurological diseases.[26]

In addition to patents, government grants also tend to exacerbate the problem. Government grants to individual researchers, usually to conduct basic research, incentivize long-term socially beneficial activities for which there is no significant market demand, either because of indivisibilities or very high uncertainty. But grants, and the administrative agencies that manage them, are structured along technological or disciplinary domains. And it is notably hard to obtain grants from a single NIH institute to do research that combines technological domains.[27] Despite some efforts to foster technology-spanning team research, my interviews with both scientists and clinicians also reveal that faulty inter-institute coordination of technology-spanning grants represents a major hurdle in conducting boundary-spanning basic and clinical research. Two additional types of incentives are worth noting: taxes and agency regulation. Tax incentives in the United States, however, and in contrast to those of other countries with intensive R&D industries, are generic—they enable firms to deduct research and development costs. Precisely because tax credits are generic, any uniform increase in tax subsidies is likely to lead to a dynamic misallocation of resources by oversubsidizing research into patentable low-hanging fruit and worsening the underinvestment in the assembly of non-traditional teams.[28] Finally, the area of regulation, in particular through the Food and Drug Administration, represents important opportunities to foster collaborative research across technological domains, opportunities that I explore in Part ___—but these opportunities remain untapped.[29]

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jointly between two or more firms are of higher quality (as measured by forward citations) than those held by a single firm, and concluding that "[t]he mentality that joint patenting is a second-best option has likely resulted in fewer R&D partnerships than what is socially optimal, as the positive trade-offs from such collaborative behaviour may not be fully recognized by firms and policymakers."); Atkinson, note ___ at 626 (arguing that, because research results from pre-competitive collaborations are often shared, "firms are less able to capture the benefits of collaborative research, leading them to underinvest in such research relative to socially optimal levels.")

26 Joshua J. Gagne & Niteesh K. Choudhry, *H M M - D I M ?*, 305 J.A.M.A. (2011). Amy Kapczinsky, *C : H G B I I*, 59 U.C.L.A. L. REV. (2012) (emphasizing that the intellectual property system's reliance on price as a proxy for the value of an invention has severe distributional effects, such as the undersupply of drugs for which there is no market in developed countries); Gideon Parchomovsky, Patent Portfolios.

27 Part ___.

28 , . ., D.J. Wilson, *B N ? I - , O - - , A E &D C*, 91 REV. ECON. STAT. 431, (2009)

29 Joshua J. Gagne & Niteesh K. Choudhry, *H M M - D I M ?*, 305 J.A.M.A. 711, 712 (2011) (proposing that once the first generic drug in a particular drug class

If understanding and finding treatments for complex diseases is, as I maintain here, in large part a problem of assembling non-traditional teams, why is it that team assembly doesn't figure prominently in accounts that seek to justify governmental intervention in markets? The main reason for this gap is the persistence of particular simplifying, but incorrect, assumptions about the types of market failure in the production of knowledge goods that justify governmental intervention.[30] The traditional justifications for governmental intervention in innovation markets assume that the knowledge required to make socially valuable innovations will be available to firms or individuals, so long as the free-rider and the lack of market demand problems are addressed. In other words, these accounts assume low or no access costs to the market for knowledge.[31] But this assumption ignores a crucial determinant of innovation outcomes, and the key force leading to underproduction of technology-spanning teams: the architecture of knowledge distribution. Scientific and technical knowledge is produced by communities of innovators that can be conceptualized as nodes in a knowledge network. Some communities have close ties with each other and frequently share information. Others, despite having both complementary and/or synergistic skills[32] needed to solve social problems, have few or no ties—they are separated by what sociologists call "structural holes."[33] As my case study illustrates, there are persistent social barriers that keep the architecture of knowledge distribution stable. Facilitating the re-distribution of knowledge relevant to solve complex problems—including complex biological problems—requires external incentives precisely because informal norms play an important role in creating and maintaining community boundaries.

One cannot recognize the challenges presented by the architecture of knowledge distribution, however, using traditional accounts of market failure. What is needed, and what I seek to develop in this article, is a conceptual

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has been approved, the FDA should require additional drugs in that therapeutic class to explicitly show superiority over available products to gain approval).

[30] Brett M. Frischmann, *A E I C M*, 89 MINN. L. REV. 917, 948–49 (2005) ("[P]ossible free riding drives analysts to focus on supply-side considerations, and more specifically, to correct market-driven supply problems by designing property-based institutions to lessen the costs of exclusion and minimize free riding.").

[31] This is a key assumption when information goods are treated as non-rivalrous. Studies in several discipline have challenged this assumption. *, . .,* Michele Boldrin & David K. Levine, *C I*, 55 J. Monetary Econ. 435, ___ (2008) (arguing that because "ideas are embodied and costly to transmit, . . . spillovers are [not] an important externality). But while most recognize that knowledge transfer is not strictly costless because tacit knowledge or know-how influences how easy it is to transfer information, this recognition is often ignored in descriptions of market failures in technological innovation or is predicted to diminish with wider access to information. *, . .,* Joel Mokyr, 2005. "The Intellectual Origins of Modern Economic Growth," Journal of Economic History Vol. 65, No. 2 (June), pp. 285-351 (describing "access costs" [to knowledge] as an important barrier to innovation but noting that access costs have decreased dramatically with the rise of the internet).

[32] Part ___.

[33] RONALD BURT, STRUCTURAL HOLES AND GOOD IDEAS.

map of collaboration that includes an account of the barriers to non-traditional team assembly. Using both original empirical research on the formation of cross-cutting teams and insight from network, geographical, and evolutionary theories of innovation, I show how informal norms in scientific and technological communities often work to keep both complementary and synergistic knowledge necessary to solve complex problems contained within communities that do not routinely interact with each other. I introduce the term "innovation scaffolding" to synthesize one of the key findings of my empirical research: creating teams that cross technological domains may require only creating temporary bridges (through policy instruments) between domains. Once new social relations form between team members, collaborations across technological domains that involve open knowledge-sharing and a high degree of trust generate high amounts of personal, intrinsic motivation, and can thus be self-sustaining. Normatively, adequately incentivizing the most socially-desirable innovations will require re-conceptualizing innovation incentives to include a scaffolding component.

The remainder of the Article proceeds in three parts. Part I reviews the traditional arguments in the intellectual property literature that justify governmental intervention in the market for innovation. In this part, I engage with the debate between IP "traditionalists" who focus on the superiority of IP to fix the free-rider/appropriability problem and "open innovation" or "knowledge commons" scholars who emphasize the production of knowledge in IP-free commons. In particular, I analyze how both these camps assume low or no barriers to the flow of information among users and producers and thus pay little attention to the problem presented by the architecture of knowledge distribution. I conclude this part by synthesizing current research on knowledge networks. This research provides a theoretical framework to explain the importance of the architecture of knowledge distribution for innovation outcomes. In Part II, I present the results of my original empirical research on non-traditional teams. Through a series of semi-structured interviews with researchers and clinicians involved in research consortia funded by NIH "interdisciplinary research consortia" grants, I describe barriers to non-traditional team assembly, catalog successful strategies to overcome them, and depict the unique social benefits that emerge from non-traditional teams. I use the results of my empirical research, together with insights from network theory to fully make the case that non-traditional team research will be underproduced by the market. As I emphasized above, an important finding that emerges from these interviews is that while informal norms create barriers for team assembly, they also serve to support collaboration in existing non-traditional teams. This implies that, normatively, creating teams that cross technological domains may require only creating temporary bridges (what I term) between domains. Part III analyzes how current innovation incentives in the form of patents and grants exacerbate the underproduction problem of non-traditional team research. It then proposes several policy levers to scaffold innovation across technological boundaries.

I. MARKET FAILURES IN THE PROVISION OF KNOWLEDGE GOODS

The intellectual property field has been marked by an important debate between those who defend the centrality of private property rights and those who emphasize the centrality of a freely accessible public domain.[34] In this part, I review both traditional analyses of information goods as public goods whose efficient production depends on private property rights and more recent challenges to these accounts by the open innovation critique. My goal is not to present a comprehensive analysis of each position. Rather, it is to emphasize how both sides of the debate tend to treat information and information goods similarly: as having the capability to flow freely across society provided they are accessible. Under this view of information goods, the key to fostering innovation is either to set information free (so that it can be part of a vibrant public domain) or to make it amenable to control by those who create it (so that the free riding problem is mitigated).[35] Put differently, neither side focuses on the problems to innovation raised by the lumpy architecture of knowledge distribution. I conclude this part by synthesizing current research on knowledge networks. This research provides a theoretical justification for focusing on the architecture of knowledge distribution, and serves as a springboard for my own empirical research on non-traditional team assembly.

A. A O I

Traditional justifications for granting intellectual property rights to innovators are grounded upon the failure of market mechanisms to efficiently supply knowledge goods. Three characteristics of knowledge goods contribute to the underproduction problem in competitive markets: (1) indivisibilities; (2) appropriability; (3) uncertainty.[36] I described the hurdles created by indivisibilities and uncertainty in the introduction, and I return to these sources of underproduction in Part ___. But the majority of the writings justifying private rights to information focus on the second factor—appropriability. The appropriability dilemma flows directly from the nature of knowledge goods. In essence, knowledge resources, which are the key component of any innovation or creative work, are characterized as public goods—non-rivalrous and non-excludable.[37] Non-rivalry (in consumption) means that knowledge resources can be enjoyed simultaneously by an unlimited number of people without diminishing any one's enjoyment of the

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34 , . ., Madison, Frischmann & Strandburg, note ___, at ___ ("Much of the scholarly debate in IP law has pitted proponents of privatization as a means of incentivizing production of intellectual goods against proponents of a widely available public domain upon which cultural goods can be built. The discussion has often devolved into a disagreement over the relative importance of incentives and access for production of ideas and creative expression.")

35 , . ., Mark Lemley & Brett Frischmann, at 264 ("On the standard law and economics account of property, technological externalities - spillovers that affect third parties - cannot be ignored. Rather, they are a bad thing that ought to be minimized if not eliminated.")

36 Arrow, note ___

37 *I* . at ___.

good.[38] Non-excludability (of benefits) means that it is difficult to exclude others from using knowledge resources (in contrast, it is comparatively easier to exclude non-paying customers from accessing real or personal property they have not paid for, such as a plot of land or an apple).[39]

The nature of knowledge resources as a public good poses a dilemma: from a static perspective (taking a snapshot of society) existing information would be put to its most efficient use if it were freely available to anyone who wants to use it.[40] But from a dynamic perspective (taking into account the effect of free access on future producers of knowledge goods), free distribution of information creates disincentives to the production of information.[41] This is because competition by "free-riders" who did not make an upfront investment in knowledge creation will prevent innovators from recouping (or appropriating) the social value of their invention, thus discouraging future innovators from investing in the creation and dissemination of knowledge goods in the first place. This is the classic type of market failure that serves as a starting point for justifying governmental intervention in the markets for knowledge. Legally enforceable private rights to information (in the form of patents) make information appropriable. The argument for patents over prizes or government subsidies centers on the market as the best (from a comparative institutional perspective) bundler of signals from consumers to producers "on the desired directions of investment and on the quantities of resources that should be committed to invention."[42] What I have called the "traditional" justification for property rights in information does make room for direct government subsidy in a subset of cases (notably, that of basic scientific research) where indivisibilities and the lack of short-term returns are predicted to make intellectual property rights inefficient.[43]

The argument that privatizing information is necessary to correct for dynamic inefficiencies in markets is complicated by the fact that knowledge is both an input and an output in the innovation process. Because innovation is a cumulative process, granting private property rights to upstream innovators impacts the incentives of downstream (or follow-on) innovators by raising the cost of building upon already existing knowledge.[44] As Mark Lemley has

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38 *I* . at ____.
39 *I* . at ____.
40 Arrow, note ___ ("[A]ny information obtained . . should, from the welfare point of view, be available free of charge (apart from the cost of transmitting information). This insures optimal utilization of the information but of course provides no incentive for investment in research").
41 Demsetz at 11 ("It is hardly useful to say that there is 'underutilization' of information if the method recommended to avoid 'underutilization' discourages the research required to produce the information.")
42 Demsetz at 12; see also Demsetz at 11 ("If, somehow, we knew how much and what types of information it would be desirable to produce, then we could administer production independently of the distribution of any given stock of information. But we do not know these things.")
43 , . ., Nelson note ___, at ___.
44 An additional layer of complexity emerges when we look beyond intellectual resources as isolated "goods" and consider their importance as inputs, outputs, and continuous

pointed out, the label "free-rider" is a mischaracterization of the innovation process where everyone can be said to "ride" upon the discoveries of those who came before.[45] The open innovation critique sought to challenge what Lawrence Lessig called the "taken for granted idea" that "control is good, and hence more control is better; that progress always comes from dividing resources among private owners; [and] that the free is an exception, or an imperfection."[46] Importantly, a group of legal academics began to call attention to examples of non-market or commons models of production that, rather than privatize information through intellectual property, shared it freely and often relied on social norms to organize the production and dissemination of knowledge goods.[47] In these case studies, ranging from open source software to Wikipedia, "the free" was not the exception but the norm. These accounts challenge the traditional narrative by negating one of its fundamental premises: that the ability to appropriate (or control) information was crucial to incentivize its production.[48]

Despite their profound differences these two approaches tend to treat information and information goods similarly—as having the capability (once disclosed) to flow freely across society. It is in whether this inherent leakiness of information goods should be encouraged or prevented, of course, that the two approaches differ. Many scholars who emphasize the crucial role of intellectual property rights in incentivizing innovation—by giving creators control over information goods they have created—build on Harold Demsetz's seminal article, .[49] There, Demsetz suggested that an efficient property system would allow owners to internalize externalities (both positive and negative) arising from their productive activities.[50] This argument, as applied to information goods, has led to an emphasis on how to snuff out the technological externalities (or spillovers) that flow naturally from knowledge goods' or information's tendency to "be free."[51] This persistent focus on spillovers in the law and economics

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constituents of complex intellectual, cultural, economic and social processes and systems. Frischmann, note ___, at 268-75; Benkler, note ___, at 37.

45 Mark Lemley, *E A E J I* , 17 U. CHI. L. REV. 129 (2004).

46 Benkler, note ___, at 23 ("To what extent will resources necessary for information production and exchange be governed as a commons, free for all to use and biased in their availability in favor to none? To what extent will these resources be entirely proprietary, and available only to those functioning within the market or within traditional forms of well-funded nonmarket action like the state and organized philantrophy?")

47 *, . .,* (cite to literature on innovation and commons: vonHippel, Benkler, Lessig, Frischmann, Madison, Strandburg, Sammuelson, Cohen, J. Boyle).

48 *, . .,* R. Polk Wagner, *I B F : I M C* , 103 COLUM. L. REV. 995 (2003).

49 Harold Demsetz, , 57 AM. ECON. REV. (1967).

50 *I* . at ___.

51 R. Polk Wagner, *I F : I M C* , 103 COLUM. L. REV. 995 (2003) ("[T]he 'fencing' of information is a remarkably futile proposition. . . . It turns out that information want to be free." . . . It is inherent in information to generate further information. The limits are primarily those of human ingenuity rather than externally placed constraints"); Oren Bar-Gill & Gideon Parchomovsky, *A M I ?* 84 TEXAS L. REV. 397 (2005)("Ironically, the very fact

literature on IP conjures up a view of information goods as naturally and easily sharable. Indeed, in his profoundly influential description of market failures in the production of information, Kenneth Arrow describes "the cost of transmitting a given body of information" as being "frequently very low." [52] And although Demsetz criticizes Arrow for not engaging in comparative institutional analysis when endorsing governmental subsidies for innovation, he nonetheless agrees with Arrow's characterization of information as "freely available" in the absence of private property rights.[53] As Julie Cohen has eloquently put it: "the uncritical assumption that information is available because it is 'out there' is one of the central failings of the mainstream economic model . . . of the public domain."[54]

My point is not that spillovers are not an important phenomenon—as Lemley and Frischmann have remarked "there is no question that inventions create significant social benefits beyond those captured in a market transaction."[55] But the focus on how information tends to spread unless controlled (by means external to the innovation process, such as non-compete agreements, contracts, and intellectual property rights) has diverted attention from all the ways in which information remains confined to the communities that produce it and those others in their close network. It has also diverted attention from studying how this confinement often has negative consequences for advances in our understanding of complex problems, including complex diseases. Indeed, what my empirical research shows is that Lemley & Frischmann were likely right when they suggested that "if anything we have . . . too few spillovers today." It is only by foregrounding the "sticky" nature of knowledge, and its uneven distribution in communities of practice that often do not interact with each other that we can begin to understand how to design innovation tools that will allow knowledge to flow more freely and productively across communities.

Scholars who study open innovation or knowledge commons, and who often oppose efforts to propertize information goods, nevertheless take

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that information by nature is 'less susceptible than all other [] [assets] of exclusive property' led to legal intervention."). Examples of this type of work include: Ed Kitch, (prospect theory); Michael Abramowicz, *D* , 92 CORNELL L. REV. (2007) (arguing for what in effect amounts for more control—in the form of a longer patent term—for a subset of inventions where the innovator is unlikely to appropriate a sufficient amount of the social benefits of his/her invention under the current regime. In Abramowicz framework more control would amount to a higher likelihood that the invention would be developed and socially useful.)

52 FRANCESCO RAMELLA, SOCIOLOGY OF ECONOMIC INNOVATION 179 (2015) (challenging Arrow's assumption that "no costs exist in the transfer and learning of knowledge by third parties," and arguing that knowledge is more akin to a "club good—an asset, that is shared privately by a limited number of subjects (a club) who may make exclusive use of it thanks to some 'mechanism of exclusion.'").

53 Demsetz, however, suggested that patents have an advantage over government subsidies in guiding the allocation of private resources to the most valuable innovations, because patents are responsive to market signals (through prices) from consumer to producers. Demsetz, note ___, at ___.

54 Julie Cohen, *C , C , C : L D ,* The Future of the Public Domain (2006)

55 Lemley & Frischmann, note ___, at ____.

a similar view of the natural shareability of information.[56] These scholars do pay attention to information's accessibility—not simply assuming its immediate availability upon disclosure. But information goods are assumed to be easily accessible provided they are not subject to private control and that technological access costs are lowered or eliminated. A central concept in the literature on open innovation is the idea of the "public domain."[57] As Pamela Samuelson and James Boyle have remarked, multiple conceptions of the public domain coexist in the legal literature.[58] But most of them are rooted in analogies to open roads and parks, or in metaphors such as "free as the air to common use"[59] that suggest a homogenous space where information resides, free for the taking. Even those conceptions of the public domain that recognize its topography and focus on its capacity to enable innovators to recombine and re-assemble knowledge resources[60] tend to assume that lack of private control and low access costs (enabled by technological advances) are sufficient to give rise to such participation.[61] For example, in his pivotal work *F I ,* Lawrence Lessig argued that a key question for the management of knowledge resources is "not whether the market or the state should control a resource, but whether that resource should remain free."[62] In turn, a resource is free if no permission is needed for its use, or if such permission is granted neutrally. Lessig focuses on how the emergence of the internet facilitates decentralized innovation by creating a commons where variously motivated individuals have the opportunity to "draw upon resources without connections, permission, or access granted by others."[63] The rate limiting step in Lessig's account is access—conceptualized as the opposite of control—once information is released from the chains of private control, individuals will " remixed films, new forms of music, digital art, a new kind of storytelling, writing, a new technology for poetry, criticism, political activism—and then, through the infrastructure of the Internet, that creativity with others."[64] In *N* , a pathbreaking work that brought the idea of "social production of knowledge" to the forefront of intellectual property studies, Yochai Benkler describes the rise of non-market models of innovation—made possible by the drastic fall in access and dissemination costs spurred by the development of the internet

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56 *, . .,* Madison, Frischmann and Strandburg, note ___, at 18 ("Private rights and private market exchange serve to limit, by law, the natural shareability of knowledge and innovation.")

57 *, . .,* [cite to law review articles and collected works on the public domain]

58 Pamela Samuelson, *E D D* ; James Boyle, *E M C D* , Law & Contemporary Probs. (2003).

59 Int'l News Serv. v. Associated Press, 248 U.S. 215, 250 (1918) (Brandeis, J., dissenting) ("The general rule of law is, that the noblest of human productions—knowledge, truths ascertained, conceptions, and ideas—become, after voluntary communication to others, free as the air to common use.)

60 Michael Birnhack, *M B ? D ,* THE PUBLIC DOMAIN OF INFORMATION.

61 Benkler, note ___ (Benkler does consider how network topology affects access).

62 LAWRENCE LESSIG, THE FUTURE OF IDEAS (2001).

63 *I* . at ___.

64 *I* . at ___.

(what I have termed technological access costs).[65] Like Lessig, Benkler focuses our attention on the choice between access and control: "To what extent will resources necessary for information production and exchange be governed as a commons, free for all to use and biased in their availability in favor to none?"[66] The low costs of technological access have changed the innovation landscape, so that "any person who has information can connect with any other person who wants it, and anyone who wants to make it mean something in some context, can do so."[67]

These accounts take the main constraints to the productive recombination and use of information to be private control and lack of technological access.[68]

structures and practices.[74] Current debates pay little attention to whether "free" or "open" information is sufficient to optimize the utilization of information resources. To put it differently, we've stopped short of asking the next set of significant questions: What does it mean in fact for information to be free of legal encumberments? How is it in fact accessed by social actors? Are there any other barriers to "accessibility"? And, switching vantage points from seeking those conditions that enable individual autonomy and creativity to those that optimize resource management, why have complex diseases resisted study and treatment?

It turns out that how individuals search for information and what of information they search for is strongly influenced by their membership in particular communities of practice. In turn, any individual's ability to combine existing knowledge—thus creating new knowledge—is often intrinsically dependent on his/her ability to interact with multiple communities of practice. In fact, studies of creativity find that individuals who are perceived as more creative have the ability to draw knowledge from distant communities that do not routinely interact with each other.[75] These individuals reside in a privileged, bridging location in the knowledge network.[76] But historical studies of innovation suggest, and my empirical research described in Part ___ shows, that informal norms in communities of practice can prevent such bridging activities by constraining both the questions asked and where to look for answers. As Julie Cohen reminds us in the context of copyright policy, "if creative practice entails the opportunistic exploitation of a set of environmental resources, copyright policy must pay close attention to the structure of that environment."[77] In the context of copyright theory, Cohen has called for a "sociology of creative practice" that is "relational and network-driven," and that recognizes that human creativity both shapes and is shaped by the cultural environment.[78] I have argued in previous work that scientific innovations should be understood as an emergent phenomenon that is inherently relational, emerging from a complex and interactive back-and-forth among researchers, often in different communities of practice or social worlds "[79] And Brett Frischmann, Michael

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74 Uzzi, note ___, at 21-24 ("Agents in creative enterprises are embedded in networks that inspire, support, and evaluate their work.").

75 , . ., Andres Sawicki, *I* (citing sources)

76 Burt note ___, at 389 ("Across the clusters in an organization or market, creativity is a diffusion process of repeated discovery in which a good idea is carried across structural holes to be discovered in one cluster of people, rediscovered in another, then rediscovered in still others—and each discovery is no less an experience of creativity for people encountering the good idea.").

77 Cohen, note ___, at ___.

78 Cohen, note ___, at 146-156.

79 , . ., Pedraza-Farina, note ___, at 839; Uzzi, note ___, at 21-24 ("This complex network, which is the result of past collaborations and the medium in which future collaborations will develop, acts as a storehouse for the pool of "knowledge" created within the field. The way the members of a team are embedded in the larger network 3 affects the manner in which they access the knowledge in the field. Therefore, teams formed by individuals with large but disparate sets of collaborators are more likely to draw from a more diverse reservoir of knowledge. At the same time, and for the same reasons, the way teams

Madison and Katherine Strandburg have emphasized the need for "a more nuanced functional account [of] the cultural environment."[80] This project is in part an effort to describe the scientific environment of those teams devoted to address complex biological questions: to map the hurdles to the successful assembly of productive cross-technology teams and to identify policy levers that can lead to successful team assembly.

The architecture of knowledge distribution creates predictable structural constraints to innovation. Describing these constraints allows us both to understand the dynamics of underproduction of complex innovations and to find ways to fix it. The next section describes empirical and theoretical work in the sociology of networks, which focuses on the importance of social relations to the process of innovation. I use network theory as a framework to explain how the architecture of knowledge distribution can lead to market failure, and as a springboard for my own empirical contributions regarding market failures in team assembly which I discuss in Part II.

B. A M F A K D

The role of social relationships in the creation, transmission and adoption of new information has long been a subject of study in sociology.[81] A growing body of theoretical and empirical research shows that the networks created by social relationships "influence the efficiency by which individuals and collectives create knowledge by affecting their ability to access, transfer, absorb and apply knowledge." These studies have collectively been termed "knowledge network" research. A knowledge network is a set of nodes interconnected by relationships. Nodes are locations in the social network where particular types of knowledge are stored. Although nodes can be knowledge elements (such as patents or products) or "non-human repositories of knowledge" (such as databases), for the purpose of this article, I will focus on the nodes that are most studied by social scientists: those composed of individuals or social collectives, such as teams and organizations. Relationships among nodes both facilitate and restrict the creation, transfer, and absorption of knowledge.[82]

Crucial insights into how social relations impact the distribution of information (and hence the direction and pace of innovation) come from work by sociologist Ronald Burt. Burt identified one particular feature in the architecture of social networks— as a key explanatory variable for the outcome of market competition—including identifying winners and

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are organized into a larger network affects how likely it is that breakthroughs will occur in a given field.")

[80] Madison, Frischmann, and Strandburg, note ___, at 665.

[81] , . ., Gautam Ahuja, *C N , H , I : A L* , 45 ADMIN. SCI. QUART. 425, 426 ("Recently, however, a few pioneering studies have explored network structure from the perspective of innovation generation"); Burt, note ___, at 352.

[82] , . ., MONGE & CONTRACTOR, THEORIES OF COMMUNICATION NETWORKS (2003); Yayavaram & Ahuja (2008).

losers in product innovation and marketing.[83] Structural holes are discontinuities in social relationships. For example, a structural hole is present when two or more communities with potentially complementary information nonetheless contain no or very few members who interact with each other across community lines. Burt hypothesized that "people who stand near the holes in a social structure are at higher risk of having good ideas,"[84] by virtue of having access to more diverse information and "alternative ways of thinking and behaving."[85] A corollary of Burt's hypothesis is that information developed within communities whose members interact routinely with each other will flow quite readily among those community members (who are connected by strong ties), but will have a tendency to remain trapped inside community boundaries. Structural holes can be conceptualized as a void in the information matrix that prevents the free flow of information among groups. Structural holes that divide clusters of dense social connections are not a rare occurrence but rather a defining feature of our social structure.[86]

The concept of structural holes provides two theoretical contributions that challenge the "free flow" assumptions behind both traditional and open source conceptions of knowledge goods. First, as Burt puts it: "information does not spread evenly across the competitive arena. It isn't that players are secretive, although that too can be an issue. The issue is that players are unevenly connected with one another [and] are attentive to information pertinent to themselves and their friends."[87] Second, the emergence of "new ideas" is strongly influenced by the lumpy architecture of knowledge distribution. In this view, innovation emerges out of a process of "recombinant search," where an individual's position in the network determines she will search for information, and of information she will have most ready access to and find most valuable. Innovators in a privileged (bridging) position in the network come up with the "best" ideas because they have access to (and thus are able to combine) diverse elements from unconnected communities.[88]

Empirical studies by Burt and others have found support for the structural holes hypothesis in multiple contexts. For example, using archival and survey data of managers in a large electronics company, Burt found that managers who broker connections across structural holes in their organization are more likely to have ideas that top managers in the

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[83] Burt, note ___, at ___.

[84] *I* . at ___.

[85] *I* . at ____.

[86] *I* . at 351 ("The defining features of the social structure are clusters of dense connection linked by occasional bridge relations between clusters." "Whether communities in a geographic region, divisions in a corporation, groups within a profession, or members of a team, people specialize within clusters and integrate via bridges across clusters.")

[87] Burt, note ___.

[88] New technologies can almost always be traced to combinations of prior technologies. *,* . . Fleming, Chen and Mingo, *C B , G C , C ,* 52 ADMIN. SCI. QUART. 443 (2007)

organization consider "good ideas."[89] Similarly, in an ethnographic study, Andrew Hargadon and Robert Sutton described how a product design firm exploited its network position as a broker among different industries to help its designers create products that "reflect[ed] the transfer of ideas to industries where they had not been used before and the creation of combinations of ideas that no one in any industry ha[d] seen before."[90] Survey research by Perry-Smith found that individuals "who occupied a structural position in the network that was associated with connections to otherwise disconnected others" (. . bridging structural holes) were more creative than those whose contacts remained inside a particular node, as rated by knowledgeable observers.[91] Using data from utility patents, Lee, Mingo, and Chen showed that an inventor "is more likely to create new combinations if he or she brokers relations between otherwise disconnected collaborators."[92]

Thus far, I have focused (as does Burt) on an individual or entrepreneur's position in the network as determining her ability to come up with good ideas. In other words, I have focused on the effect of an individual's social network on her own creativity. But there is a limit to the ability of a single person to successfully recombine elements from distant communities, even if she has social connections to members in these communities. There are two reasons for this: first, any individual will be cognitively limited in her ability to understand disparate fields of study.[93] Second, there is the problem of tacit knowledge. Acquiring expert skills in any given field requires "learning by doing"—that is, embeddedness in the relevant community of experts. It will be rare for a single individual to have access to both codified and tacit knowledge from more than two or three disparate communities of practice.[94] These limitations are of course magnified in the context of complex problems that require understanding and embeddedness in not just two but three or more disciplines.

Understanding these two limitations has shifted the focus in social network studies from the work of individuals to that of teams.[95] Finally, researchers have begun to study how team performance is affected both by the diversity of expert backgrounds and by the degree of trust among its members. Team diversity is predicted to increase team performance by bridging structural holes. And the level of trust among team members is predicted to impact the willingness of team partners to disclose information

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and accept each others' ideas.[96] Trust and diversity, however, often work in opposite directions—trust increases as background diversity decreases. Teams whose members belong to the same research tradition—that use the same research tools and prioritize similar research questions—will enjoy higher levels of trust than teams whose members have diverse expert backgrounds. But excessive cohesion in such teams hinders "the circulation of non-redundant knowledge and the production of original ideas, and instead favors group conformity."[97] The bridging ties of diverse teams avoid this problem by ensuring that non-redundant, complementary knowledge is available to the team. At the same time, diverse teams are less likely than homogeneous ones to enjoy high levels of trust because membership in different research traditions—with their accompanying different research tools and priorities—is likely to create communication and coordination difficulties. Therefore, assembling and working in non-traditional teams is predictably difficult.[98]

Empirical studies of teams also show that the ideal team composition depends on the type of problem being studied: when dealing with unfamiliar problems, high diversity (. . a higher likelihood that the team will fill a structural hole) is more effective than a homogeneous team.[99] In contrast, more conventional problems are often best solved by homogenous teams within a particular knowledge community with a high level of trust arising from a strong, shared knowledge base and research norms.[100] This research suggests that non-traditional teams that can bridge multiple structural holes are particularly well-situated to address complex problems (including complex diseases). Indeed, there is mounting empirical evidence that innovation considered a "breakthrough"[101] in any given field often arises from atypical combinations of existing knowledge from disparate communities, as well as from unusual collaborations. For example, Uzzi et al demonstrate that scientific research that assembles novel combinations of previous work tends to have a greater impact than more conventional research.[102] Similarly, Fleming et al show that patents with novel subclass combinations are more influential than patents that make more conventional

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97 Ramella, note ___, at 137.

98 [Explain why trust and diversity are in opposite directions. Cite also empirical studies that show that both trust and bridging ties are necessary for successful team performance.]

99 Using data from utility patents granted from 1975 to 2002, Lee, Mingo and Chen were able to plot the careers of over two million inventors. Their research showed that teams with more diverse ties to outside communities came up with more unusual combinations—measured as novel combinations of previously uncombined patent subclasses. Lee, Mingo & Chen, note ___, at ___.

100 Ramella, note ___, at 83.

101 Typically, breakthrough innovations start the cycle of technological change (e.g., the polio vaccine, personal computers). Over time, incremental innovations in form of new features, extensions, variations or complements to an existing product line (e.g., needle-less vaccine delivery systems, laptop computers) build on the dominant designs created by breakthrough innovations.

102 Uzzi et al., note ___, at 471.

combinations,[103] and Shi et al show that patents citing diverse (i.e. unusually combined) subclasses also have more impact than their more conventional peers.[104]

Thus far, I have summarized research in the field of knowledge networks that supports the following three key points. First, the lumpy architecture of knowledge distribution limits innovators' search space and influences their search strategy. Recognizing these barriers to the "free flow" of information is therefore crucial to understand the pace and direction of innovative activity. Second, individuals or teams who can bridge two or more otherwise disconnected nodes in the knowledge network are more likely to come up with "creative" or "breakthrough" innovations than those located at the nodes themselves. Third, boundary-spanning teams play a central role in addressing unfamiliar problems in new research areas.[105] Each one of these three points highlights the importance of understanding the dynamics of team assembly for designing effective innovation law and policy.

The knowledge network literature, however, has paid insufficient attention to identifying and documenting the barriers that maintain structural holes and make it difficult to assemble non-traditional teams, as well as the individual motivations that drive innovators to assemble and participate in such teams despite these barriers. How does brokerage emerge? And why are brokers so (relatively) rare?[106] The literature has also left unexplored the benefits created by boundary-crossing teams that may not be fully captured privately by individual team members. Research has focused instead on identifying the private benefits of teams[107]—as measured by the number of patents granted, different products introduced to the market, or changes in market share. Finally, knowledge network research has not analyzed how policy instruments (such as patents and grants), informal community norms, and institutional contexts influence the structure of the knowledge network itself. What is the role of formal and informal policies on both enabling and preventing the formation of boundary-crossing teams?[108]

These questions are particularly important to the patent law and innovation literature, because their answers should inform the design of laws and institutions involved in innovation policy. Answers to these questions are also crucial to fully develop my argument for the underproduction of non-traditional team research. As I noted in the introduction, the case for underproduction is particularly strong in the case of research carried out in non-traditional teams. The next section presents the results of my qualitative

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[103] Fleming et al., note ___, at 462.

[104] Shi et al., note ___, at 4.

[105] [Define what I mean by unfamiliar problems]

[106] [Mention concept of boundary object and boundary spanning from STS.]

[107] Of course, private benefits can also reflect social benefits, but the literature has left unexplored the more diffuse (yet equally or more important benefits, from a social perspective) social benefits of team research.

[108] Corey Phelps, Ralph Heidl & Anu Wadhwa, *K , N , K N* , 38 J Mgmt. 1115 (2012) ("The knowledge networks research we reviewed is under-contextualized in that nearly all of it overlooks the influence of the broader formal and informal institutional context on knowledge network processes and outcomes.")

case study research of non-traditional teams. I rely on findings from the case study—combined with data from other studies–to build the case for underproduction.

II. THE UNDERPRODUCTION OF BOUNDARY-SPANNING INNOVATION

A. E E

Qualitative case studies of non-traditional teams provide evidence that is hard to extract from quantitative analyses. Narratives of team formation (elicited from interviews with key actors) can begin to address the of team building: How did the idea to form a team emerge? What were the stages of team formation? Were there any barriers to team assembly? Why did researchers seek to work in a team? How did individual participants experience working in a team? How did key players conceptualize the role of patents, grants, informal norms or other policy instruments in assembling and maintaining (or preventing the formation of) a non-traditional team? Qualitative case studies can also serve to regarding team assembly and performance, which can later be tested using other methods. These types of evidence are important to begin to address the gaps in the knowledge network literature outlined in the previous section.

In order to trace the process of non-traditional team assembly, I studied boundary-spanning teams sponsored by the NIH's Roadmap for Medical Research Initiative (Roadmap) between 2005 and 2012. The Roadmap was launched in 2002, under the leadership of then-Director Dr. Elias Zerhouni, with the goal of "reconfigur[ing] the scientific workforce by encouraging novel forms of collaboration."[109] It was the result of several rounds of consultation with stakeholders, scientists, and health care providers, who were asked to identify major opportunities and gaps in biomedical research that no single institute at NIH could tackle alone.[110] One overarching theme emerged from these consultations: understanding the puzzle of complex diseases would require the expertise of nontraditional teams with divergent perspectives that cut across traditional disciplines.[111] The Roadmap was launched to identify (and fund) potentially transformative research requiring collaboration and coordination across NIH institutes and across traditional scientific disciplines.[112] The Roadmap funded nine teams (or research consortia)—out of a total of___ applications.[113] The consortia

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[109] Elias A. Zerhouni, *B : B , , C* , 294 JAMA 1352, 55 (2005).

[110] *, . .,* Elias A. Zerhouni, *NIH* , 302 SCIENCE 63 (2003).

[111] *, . .,* Elias A. Zerhouni, *NIH M* , presentation delivered on February 27, 2004, slide 13, http://www.webconferences.com/nihroadmap/ppt/02%202-27%20RM%20webcast%20EZ%20final%20v.4.ppt

[112] Zerhouni, note 110, at 63.

[113] SysCODE: Systems-based Consortium for Organ Design and Engineering; Genomic Based Drug Discovery; Interdisciplinary Research Consortium for Geroscience; Northwest Genome Engineering Consortium; The Oncofertility Consortium: Fertility Preservation for Women; Neurotherapeutics Research Institute; Consortium for Neuropsychiatric Phenomics;

ranged in focus from the study of new ways to regenerate organ parts from stem cells (combining developmental biology, engineering, and computational approaches) [114] to research into fertility preservation techniques for young cancer patients through the Oncofertility Consortium (bringing together reproductive endocrinologists, oncologists, molecular biologists, biological engineers and cryobiologists).[115]

I focused my research on the Oncofertility Consortium, which was founded to address the unmet need of cancer survivors (and in particular female survivors) for fertility preservation options at the time of diagnosis. The consortium represented an ideal candidate to study non-traditional team formation because it sought to bring together diverse basic science as well as clinical research communities that had traditionally not collaborated with each other and where collaboration would have clear benefits to patients. I conducted semi-structured interviews with twenty key informants, attended conferences and participated as an observer training sessions for new members. A full description of the methodology employed in my case study can be found in Appendix A.

In the next four subsections, I provide examples of how: (1) there are particularly high barriers (or high fixed costs) to the assembly of non-traditional teams; (2) the type of spillovers generated by non-traditional team research are of high social value and unlikely to be fully appropriated by individual team members; (3) non-traditional team research is particularly risky and uncertain; (4) despite barriers to team research that arise from both informal community norms and the inadequacy of policy incentives, once new social relations form between team members, collaborations across technological domains that involve open knowledge-sharing and a high degree of trust generate high amounts of personal, intrinsic motivation, and can thus be self-sustaining.

1. Barriers

As cancer treatments have become more sophisticated and effective, the number of cancer survivors—and in particular childhood cancer survivors—has increased worldwide.[116] But research on the impact of cancer therapeutics on male and female fertility, as well as research on fertility preservation techniques for females, has lagged behind. So has the availability of fertility services for newly diagnosed cancer patients: at the time of the grant, the infertility industry was structured to deal exclusively with planned in-vitro fertilizations but not equipped to offer emergency procedures. And despite the rising numbers of patients living cancer-free, treating oncologists seldom discussed the treatment's effect on fertility, or options for fertility

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Taskforce for Obesity Research at Southwestern (TORS); Interdisciplinary Research Consortium on Stress, Self-Control and Addiction.

114 https://commonfund.nih.gov/Interdisciplinary/consortia; https://commonfund.nih.gov/Interdisciplinary/consortia/syscode

115 https://commonfund.nih.gov/Interdisciplinary/consortia; https://commonfund.nih.gov/Interdisciplinary/consortia/oncofer

116 Reis, LAG.; Eisner, MP.; Kosary, CL., et al., editors. SEER cancer statistics review, 1973–1999. Bethesda, MD: National Cancer Institute; 2002.

preservation with their patients.[117] At the time of the grant application "there were no women, zero, who were getting fertility counsel."[118] This was the case despite studies showing that cancer patients rank fears of losing their fertility second only to those of facing death.[119] As a result, many cancer survivors were confronted with a second devastating diagnosis: that of infertility resulting from their cancer treatments. One fundamental reason for this disconnect between the needs of cancer patients and research and treatment priorities was the lack of communication and collaboration between oncologists and reproductive endocrinologists.

The reasons for the disconnect between these two communities are likely manifold, but two in particular represent a common thread across all interviewees: and . First, the priorities of the oncologists' and endocrinologists' research communities differed. Oncologists' focus on understanding the mechanisms of cell proliferation and cell death (the hallmarks of cancer) meant that there was scant research into the fertility effects of cancer chemotherapeutic agents for different populations—and thus little information to give patients as to the effect of chemotherapeutic drugs on their fertility.[120] The perception of one Oncofertility consortium member captures what was reported by a majority of interviewees: "I find that in our area anyway the oncologists are a little bit resistant to participating in studies such as these, it's not really high on their list of priorities."[121] Partly as a result of this lack of research into (and lack of familiarity with) the effect of fertility hormones on cancer progression, there was also a widespread assumption in the oncology community that hormones that would be used to stimulate egg production for fertility preservation were counter indicated for women with cancer. For example, a principal investigator in the oncofertility grant (PI) described a key hurdle to getting oncologists interested in fertility preservation as follows: "Oncologists thought hormones cause cancer. So, there was this notion that hormones are bad. And, they're not. And they're not causing cancer. This was just this kind of zeitgeist."[122]

At the same time, reproductive endocrinologists did not routinely treat cancer patients; rather, they were used to treating generally healthy patients whose only diagnosis was infertility–and their research priorities aligned with the priorities of this subpopulation:

> If you go into an infertility clinic, the vast majority of patients that you're gonna see in that waiting room are women, over

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[117] Oncofertility grant, page 134.

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[119] Carrie L. Nieman, Karen E. Kinahan, Susan E. Yount, Sarah K. Rosenbloom, Kathleen J. Yost, Elizabeth A. Hahn, Timothy Volpe, Kimberley J. Dilley, Laurie Zoloth & Teresa K. Woodruff, *F A C : L A C C*, 138 CANCER TREAT RES. 201, (2007).

[120] "[M]edical oncologists are not aware of the precise reproductive threats of their treatments on reproductive outcomes and clinical reproductive endocrinologists do not routinely treat cancer patients." Oncofertility grant page 137.

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[122]

> the age of 35, who've been trying to get pregnant for a long time and are typically very well and very healthy patients. They're dealing with infertility, which is a horrific diagnosis and it is hard to deal with, but for the most part that's their main concern. . . . When we're talking about oncology, we're talking about very acutely sick patients. Sometimes, the patient's so sick that they're in-patient.[123]

Second, oncologists and endocrinologists had developed that had become . Addressing fertility preservation required a significant modification of these established practice routines. For example, a clinician member of the consortium remarked:

> There are individuals who have styles of practice. The issue for oncologists is living or dying. From the outset you see patients for cancer, the team says so and so has this cancer, and it's very hard and you don't know how much they have to live. . . . My colleagues in oncology, they are so busy and they are so much dealing with living and dying issues. How to treat the cancer, what kind of cancer is it. They are getting pulled in all different directions about taking the cancer out. So, the thought of fertility preservation has not been one to rise to the top of the soup for a long time. Talking about fertility preservation is not in their agenda. They are not trained to do it. The questions that are going to come out they are not ready to answer.

Another interviewee explained that the practice styles of the oncology community had not changed to reflect the evolving reality of cancer patients:

> These physicians had in-bred biases about how to deliver care to these patients. And those biases ran again from 'Don't bother her, she's got enough on her mind right now, my focus is on getting her well. Don't worry about the esoteric stuff, she can't afford this. Don't even bring it up,' to my favorite 'Adoption is always an option,' which we knew from our research was not the case. But they had all these biases that came from old school kinds of treatment and the fact that they hadn't re-calibrated their thinking to the fact that these were diseases that killed people in the last generation so we didn't have to worry about them.

On their end, endocrinologists had developed treatment routines tailored for otherwise healthy women with an infertility diagnosis. As explained by several consortium members: "Most IVF places have a programmed and linear way of bringing people through an IVF cycle. Patients are taken through step-wise. Now we have patients who need to be shunted into IVF tomorrow afternoon. We are used to consumer-driven type of care, this group is more of an emergent-care, medically driven type of

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care."[124] For this reason, tailoring both research and medical care to oncology patients required a radical reorganization of the practice routines of reproductive endocrinologists:

> As a fertility specialist, I'm asking you now to see a patient the same day. I don't care if you have a three-month waiting list. This patient's not waiting. You're gonna see them right now. I'm asking you to take care of a patient who might be sicker, her blood counts might be different than what you're used to seeing. I'm asking you to step outside of your comfort level of having normal healthy patients and seeing someone who is not so perfectly blood count wise normal. And make sure you're okay with that.[125]

Both barriers to collaboration—research priorities and entrenched practice styles—emerge from informal social norms that developed in both research communities. These social norms in effect kept isolated knowledge relevant to solving a problem at the intersection of both communities.[126] In the language of social networks, oncologists and reproductive endocrinologists occupied two separate nodes in the knowledge network, separated by a structural hole. The main driver of the Oncofertility grant application, a reproductive endocrinologist, occupied a privileged position in the knowledge network— . . in a structural hole—when she became the Director of Basic Sciences for the Robert H. Lurie Cancer Center at Northwestern University.

Crucially, these barriers not only prevented working on a common problem (fertility preservation) but also prevented the realization that there was a problem to begin with, that required the joint efforts of both communities. As a principal investigator in the original grant application emphasized: "You had issues on both sides of the equation so it wasn't that there was a fault line. *I* ."[127]

2. Spillovers

It is well documented that the social benefits of many research and development activities exceed their private benefits. But not all spillovers are created equal: spillovers that emerge from non-traditional team research are particularly socially significant. My interviews with Oncofertility team members identified three specific types of spillovers that lead to important social benefits that cannot be fully appropriated by team members: problem finding; creation of new social networks, and the reduction of uncertainty

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126 These findings are consistent with evolutionary economics theories of innovation, which predict that "how much the behavioural firm spends on innovation , including those for determining its profit mark-up on costs and the proportion of sales revenue that it allocates to R&D and other innovative activities (Kay, 1984)." J.S. Metcalfe, *E E* at 934.

127 [emphasis added]

about doing research at the intersection of oncology and reproductive endocrinology.

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Sociologists of innovation differentiate two types of innovative activity: and . The shorter, - process occurs when the problem to be addressed is already known within the community. Solving it is "thus a matter of finding and organizing the correct solution."[128] In contrast, the longer - process "is deployed when faced with problems that are less known and which may even become problematic thanks to the insight itself. This second mode is associated with paradigm shifts and the more significant kinds of discovery."[129]

Interviews with researchers in the Oncofertility Consortium revealed several instances of unexpected that emerged from the new interactions among scientists from different research traditions. Conceptualizing the need for research in what is now called the field of oncofertility is itself an example of "problem finding." As interviewees recount the process of team assembly, the original problem finding insight was a case of brokerage: the principal investigator for the Oncofertility grant, herself an endocrinologist, became the head of a cancer center and therefore had access to complementary information from both disciplines. But Oncofertility researchers recount many additional cases of that emerged precisely because basic researchers from multiple disciplines (biomedical engineering, oncology, reproductive endocrinology, and primate biology) worked together to stimulate the growth of follicles , and shared their findings in monthly laboratory meetings.[130] In other words, interviewees reported that these problems would not have been discovered (or would not have been discovered as quickly) but for the boundary-crossing interactions facilitated by the Oncofertility Consortium.

The following passage from a researcher working with monkey ovaries vividly recounts how the team quickly came to recognize a problem with follicle growth in monkeys that could not be observed in rodents (the most popular model used in the laboratory by basic researchers) and that more closely resembled the situation in human ovaries:

> What we found for example was that some of the follicles would actually just sit there and look at you. And then you had others that would grow over the five weeks and turn into these beautiful, gorgeous antral follicles. And you'd say, 'What's this heterogeneity? Do you see this in the rodent?' And they [researchers working on a rodent model] would go, 'No.' . . . Then you think, 'Well, so how does this relate to follicles from humans? We found if we took follicles from young, reproductive age monkeys—what would be

[128] Ramella, note ___, at 82.
[129] *I* .
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> considered 20 year olds in humans—they did really well, would give us a lot of those large growing follicles. If we took them from the animals, that were over 15 years of age, we didn't…And we thought, 'Well, what did this mean for the cancer patients that's 40 or 35 as opposed to 20? It made us think on a much broader scale and made us think that immediately because we were having these tremendous and exciting lab meetings every month.[131]

What is important to recognize is that this example of problem finding required more than a preferred network position with access to data from both fields, which could then be combined to make a new discovery (as brokerage is conceptualized in Burt's model). Rather, knowledge about new problems emerged from the regular interactions and sharing of raw data between multiple communities—it was a synergistic, emergent property of relationships across communities.

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The Oncofertility Consortium brought together scientists from different disciplines to focus on the question of in vitro follicle growth, and build a referral network from oncologists to reproductive endocrinologists. From those initial connections and that initial question, however, a new set of unpredicted relationships and collaborative research ventures emerged. For example, one of the reproductive endocrinologists working with monkeys continued and expanded a collaboration with cryobiologists—originally designed to improve methods to freeze ovarian tissue: "I branched into 2 totally new collaborators in cryobiology who have other mathematical models and things that will be useful to our research that I didn't know before and we were very willing to apply their theoretical problems to something in biology. So, it's just grown into our own little mini group focusing on the cryobiology of ovarian tissue." [132] Another researcher remarked how the team grant allowed her group to dramatically expand her research network: "You can have all these great ideas and again we probably could've gotten a grant by ourselves to do this basic science. But, put[ting] it in a larger context is everything and it allowed us to be able to interact with Teresa's group, to interact with bioengineers, to interact with these cryobiology people that we never would have done on our own."[133]

More broadly, the new connections and research programs established through the short-lived NIH grant were surprisingly resilient—initial team members continued and expanded their collaborations with other scientists outside their fields and outside the United States. These findings are consistent with empirical studies that find that past collaboration is a

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133 Additional quote: "Maybe if you don't do a basic science project with one or two of these people ever again, it's open you up to new areas and new ways of doing things"

good predictor of whether a firm will enter into collaborative agreements in the future.[134] Experience with collaborative activities appears to create a virtuous cycle that increases the likelihood of future collaboration.

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Doing research at the intersection of multiple fields can lead to creative new solutions to existing problems, and to finding unexpected new problems to be solved. And it can also reduce the inherently high uncertainty associated with exploratory research at the intersection of multiple fields. In the case of the oncofertility consortium, the original NIH Roadmap grant, which coined the word oncofertility, gave rise to a new field that the American Medical Association now considers a new medical discipline. The social impact of this shift was dramatic. Prior to this work very few oncologists were counseling cancer patients on fertility preservation options, and were making referrals to endocrinologists prior to cancer treatment. And very few basic researchers were working at the intersection of bioengineering and reproductive endocrinology. The creation of the new field of oncofertility, and the publication of findings that an engineered matrix could be used to grow eggs , created a cadre of new researchers and practitioners dedicated to research at the intersection of oncology and endocrinology. More broadly, even in cases where the new social links don't result in the creation of a new field, and therefore a new node in the knowledge network, successful exploratory research at the intersection of different research communities will invariably provide more data about the feasibility of research going forward.[135] Indeed, dramatically reducing uncertainty is a hallmark of non-traditional team research. As one principal investigator of the Oncofertility grant remarked:

> This opportunity was transformational. Absolutely, because otherwise I was doing ordinary science. So having that grant mechanism has created now a solution for so many patients. This is exactly what you want bench science to do. You want bench science to be able to communicate directly into patients' lives. And ordinary science doesn't do that because you don't have the capacity to do that. It's usually bench to publication to grant and back. Ordinary sounds pejorative but I don't wanted to say it pejoratively. I think it's just the way the mechanisms are.[136]

Similarly, a consortium member who worked with primates observed:

> The advances that have been made because of that funding mechanism are just incredible. From the molecular biology side, from lots of other clinical problems. Again, bringing

134 *, . .,* Powell, note ___.
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> together people who normally would not work together, to take that giant leap. I think that each of our different areas spurred each other on to see that grander vision about how we could get this going a lot faster and serving a lot more patients a lot faster as well.[137]

3. Uncertainty

Research outcomes from the Oncofertility Consortium research were particularly uncertain at its inception. In fact, the principal investigator for the oncofertility grant had tried, unsuccessfully, to obtain funding from more traditional NIH sources (such as RO1 grants).[138] These applications were systematically denied because, when viewed from the perspective of NIH funding committees, the outcome of the experiments aimed at growing eggs and ovaries was too uncertain, too unexplored, to merit funding when compared to other more predictable projects.[139] Funding through the Roadmap grant aimed, among other things, to fund riskier (. . more unpredictable) projects at the intersection of multiple fields that could not be funded by traditional NIH grants. Despite this, the oncofertility consortium met increasing resistance from grant administrators who did not take into account the high degree of uncertainty involved in doing research at the intersection of different fields—a degree of uncertainty that would often lead to having to change course in what was proposed in the original grant. As one principal investigator explained:

> [The NIH administrators were] very stuck in whatever was written in the original grant. It's what you were supposed to do and you could do no more. And I kept arguing that ‘
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> , ,
> .’ And those other things were not off target. They were on a trajectory that we could see. And so they were really stuck on the notion that, and I called it the old testament, that all we could do was what was in the old testament or the original constitution. So, that took a lot of my time just justifying the kind of science that was happening because science was happening very fast.[140]

Another interviewee similarly criticized the NIH for its inflexibility and unwillingness to adjust its expectations to research in an evolving new field:

> The NIH leadership and direction of this program was dismal. . . . [We] would often get comments back: ‘Well, those studies that you're doing are not in the grant. You can only do what's exactly in the grant.’ Well, you know, that's not the

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140 [emphasis added]

> way research works… and you know, you may put in there you're gonna do this particular study. [But] we may culture follicles one way and it doesn't work, so we culture them in a different way. They basically expected us to follow the letter of the grant for everything we did and it was a struggle.[141]

As explained in the interview excerpts above, the reasons why oncofertility research was unpredictable ante were twofold. First, because oncofertility was a new field that combined scientists from multiple research traditions, new research problems and roadblocks emerged with more frequency than would be expected in "ordinary [team] science."[142] This often required changing course and devising new research plans. There is a clear increased risk in doing research that is likely to run into roadblocks that may not be successfully overcome. Of course, in the case of successful non-traditional team research, these roadblocks gave rise to important social benefits—namely the three types of spillovers described in ___. But it is hard to predict which teams will and will not succeed.[143] Second, oncofertility research was rather than .[144] It focused on discovering new facts about the effect of different cancer treatments on fertility, and on developing new techniques (based on the combination of reproductive endocrinology techniques and engineering principles) for culturing follicles . It did not focus, at least not at its inception, on scaling up and improving well-known techniques and procedures. The focus on new basic scientific discoveries, and on the development of new research tools, is a hallmark of non-traditional team projects—especially when they are first established, as two or more communities of practice begin to merge their approaches to solve a newly-identified common problem. Exploratory research, however, is more uncertain than research aimed at exploiting known techniques.[145] These two reasons are of course related: new research problems and roadblocks are likely to emerge with more frequency in non-traditional team research precisely because non-traditional team research is more likely to be exploratory rather than exploitative.

4. Intrinsic Motivation

One important unanticipated finding emerged from my interviews—a finding that was shared by fourteen out of the fifteen key informants that I interviewed: the intrinsically motivating power of working across boundaries. I call this finding "unanticipated" because my interview outline did not contain specific questions about how the participants themselves experienced non-traditional team research. I wanted to know about the barriers to collaboration (or lack thereof), how these barriers emerged, how they had been surmounted, about the role of policy incentives and informal norms in

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143 [Note that my research uncovers some hallmarks of successful teams.]

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both overcoming and creating these barriers, but had not considered the possibility that collaboration across boundaries itself would be a powerful incentive. Of course, this is why qualitative interviews can be very useful: they can help us formulate new hypothesis about our topic of interest.

It was as soon as I had interviewed the first scientist on my list that I was struck by the excitement and emotional energy that these scientists associated with their time spent doing research in the Oncofertility consortium. As the excerpts below indicate, this excitement and motivation arose, in part, from working with scientists from different disciplines in an open environment where raw data was routinely shared.

For example, one scientist considered his experience participating in monthly lab meetings with colleagues from other disciplines, trying to crack the problem of egg maturation in vitro as "one of the great highlights of [his] career."[146] Another one noted: "it was one of the best efforts I've been involved with in terms of science. Working with a team was fun. . . [There was] tremendous cohesion, tremendous collaboration and absolutely everyone got excited by everybody else's discoveries. It was wonderful. It had humanism, science. It was incredible."[147] Similarly, a reproductive biologist who worked with rhesus monkeys characterized his participation in the program as "easily the best program that I was involved in, well, 40 years of research." He went on to add: "it was just tremendously exciting and progressive. And it included reproductive biologists, matrix bioengineers, cryobiologists and top of the line clinical scientists."[148] Yet another scientist, with a long research trajectory preceding the consortium remarked:

> Amazing is a very overused word but that says it as well. So, you do your research in your lab and it's pretty specialized and pretty basic and you get together with your big professional society every year to talk about your results and you're kind of this little fish swimming around in this big pond, but you're all part of the same ecosystem and making these little advances that are still important. Then you get to this consortium where you have access to all of these people in different areas and even outside of the science . . . to pitch in towards this common goal, and to share just data, to share fears, to share successes was just the most rewarding experience I've had in science, so far.[149]

Basic scientists also attributed their high levels of intrinsic motivation to the opportunities created by the structure of the oncofertility consortium

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149 Interviewees considered openness in data-sharing to be very important. One interviewee added: "[W]hat I loved about it was the openness of the sharing of data. You can't make advances unless you can share what you found and . . . And then that is infectious among people who share a similar science personality and it makes it very, very fun as a part of your career and also is critical for advancing the field."

to interact with clinicians and their patients. In the words of one principal investigator:

> "I think fundamental knowledge is critical . . . But it also is really critical when you can then leap into clinical care. At our oncofertility meetings, part of the stuff that's not on the videos, [is] when we have patients come in for the evening receptions, I have all my students come and listen to these patients because that's the tangible face of what your work means, and I want them to know that, I want them to see that value, even though they're doing this little thing that will just become an abstract. . . . I want them to be connected to the larger value, and the patients as well, they come in and will talk to students and they'll stand at their posters and that inter-relationship is something that I think just changes everything. It changes the way you look at what you're doing and we just don't have enough opportunities to do that. That's not a part of ordinary science."[150]

This finding suggests that interaction with peers who employ different methodologies and bring a different knowledge base to the study of a particular problem be intrinsically motivating and thus incentivize team members to continue working in a boundary-spanning collaboration.[151] It also suggests that assembling successful non-traditional teams may need only a temporary structure—a "scaffolding"—that is able to bridge the structural holes and social barriers keeping the knowledge base from the different communities apart. I return to these findings in the last section of this article, when I engage with policy proposals.

I concluded the first part of this article by highlighting how existing studies in the knowledge network literature fail to address several questions that are important, from a policy perspective, to understand both barriers to non-traditional team formation and the likely effects of policy levers. The results of this case study shed important light on these questions, and provide necessary evidence to more fully build the theoretical case for the underproduction of non-traditional team research. To sum up: (1) it is likely that structural holes among different communities are often maintained by informal social norms that emerge in each community of practice. In the particular case of the oncofertility consortium, clashing research priorities and settled research practices prevented their coordinated study of fertility preservation in cancer patients. It is precisely

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[150] The same scientist also noted: "I think that is part of the gravitational force because you know that you're doing something that matters. And we wouldn't have been able to do that if we just all were doing our own thing. We had to set up this larger infrastructure. We had to set up the clinical side."

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because informal norms tend to keep research communities relatively isolated from each other that external incentives are likely necessary to foster research at their intersection. (2) There are three important social benefits to boundary-crossing teams that are distinct from those resulting from research carried out by homogeneous teams or solo inventors: (a) problem finding; (b) creation of new social networks, and (c) reduction of uncertainty about doing research at the intersection of multiple fields. These social benefits are positive externalities or spillovers: social benefits that are unlikely to be fully appropriated by the particular team research that generated them. (3) Because non-traditional team research tends to be exploratory, it is particularly risky and uncertain.

In the following section, I rely on these findings and data from additional studies to fully build the case for the underproduction of non-traditional team research.

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1. Underproduction in the Traditional Economic Model

To understand why non-traditional team research will be underproduced by a perfectly competitive market, it is helpful to review the standard economic justification for governmental intervention in the market economy to foster innovation. This standard justification begins with the recognition that the essential character of innovation goods, that differentiates them from other commodities, is their informational content. It is this informational content that determines the market value of the products of innovation. As Kenneth Arrow theorized in 1962, information goods have three characteristics that predict they will be produced at a level below what is socially optimal in a perfectly competitive system: (1) indivisibilities, (2) inappropriability, and (3) uncertainty.[152] I examine each one of these characteristics below.

Certain R&D projects are indivisible and require too large an investment to be undertaken by private firms. Consider, for example, building and operating the Large Haldron Collider.[153] Studies estimate that finding the Higgs boson cost 13.25 billion dollars.[154] The Haldron Collider is an indivisible good: it cannot be divided into smaller units that can be sold in the market to consumers, and consumers are unlikely to band together to coordinate its purchase. [155] As a consequence, absent governmental

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152 Kenneth Arrow in Nelson, R. (ed.), *D I A*, Princeton University Press (1962).

153 http://home.cern/topics/large-hadron-collider

154 Alex Knapp, *H M D I C F A H B ?*, Forbes, July 5, 2012.

155 *, . .,* Daniel Sutter, *G , I G M F*, 8 ECON. & POL. 133, 134 (1996) (showing that consumers will fail to form groups to share in the purchase and consumption of an indivisible good, when that good is highly indivisible). [Add note on club goods.]

intervention, the market will have no incentives to build and operate the Haldron collider, despite it being welfare-enhancing. Many basic research projects, especially those requiring large investments in infrastructure, present an indivisibility problem.[156]

The appropriability problem can be summarized as follows: the process of innovation consists primarily in the creation of knowledge about how to make new goods and provide new services. Because producing this knowledge has large upfront fixed costs, innovators will only invest in research and development if they can appropriate a sufficient amount of the returns to their investment.[157] At a minimum, innovators need to recover the fixed costs involved in the knowledge contained in the innovation (. . research and development costs), not just the costs of the information-containing good (. . manufacturing costs). But information goods are non-rival: use by one firm does not prevent simultaneous use of the information contained in them by another firm.[158] Information goods are also non-excludable because non-paying consumers cannot easily be prevented from accessing the information contained in them.[159] As a consequence, absent the ability to keep information secret, innovators cannot recoup research and development costs simply by selling their information-

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156 , . ., Brett Frischman, *A E I C M* , note ___ at 969.

157 Another important argument that anything other than full appropriability of the outputs of innovation will lead to underproduction centers around the role of market as a bundler of demand signals. In this model, if a producer of an information good is able to appropriate the full social benefit of his/her invention, he/she will have a perfect signal of market demand for his/her product and thus be able to produce the good accordingly. See Harold Demsetz, *I E : A* , 12 J. Law and Econ. 1 (1969). It follows that absent full appropriability, the information good will be underproduced. This line of thinking has led scholars to endorse strong intellectual property rights on the grounds that they would come closest to the full appropriability optimum. *, . ., G , C ' H (N : H & , 1994), . 178-79.* There are, however, several problems with this line of thinking. First, incomplete appropriability is a reality in areas of human creativity. As William Fisher has remarked, seeking full appropriability by granting strong intellectual property rights "might refine the signals sent to the creators of different sorts of fiction, drugs, and software concerning consumers' preferences, but would lead to even more serious overinvestment in intellectual products as opposed to such things as education, community activism, and primary research." William Fisher, *I I : , E H ,* INDUSTRIAL PROPERTY, INNOVATION, AND THE KNOWLEDGE-BASED ECONOMY, BELEIDSSTUDIES TECHNOLOGIE ECONOMIE (Ashgate, 2002). For additional arguments on why incomplete appropriability can be socially beneficial Brett Frischmann & Mark Lemley, Spillovers, supra note ___.

158 Provided the firm possesses relevant know-how or absorptive capacity to practice the innovation and to reverse engineer the information contained in it.

159 , . ., Arrow, note ___, at 614 ("[T]he cost of transmitting a given body of information is frequently very low."); Joel Mokyr ___ ("Technology, like all forms of knowledge, is non-rivalrous, so that the social marginal cost of sharing it is zero."); R. Polk Wagner, *I B F : I M C* , 103 COLUM. L. REV. 995, 998 (2003) ("The 'fencing' of information is a remarkably futile proposition . . . It turns out that information 'want to be free.'). –.

containing goods in the market.[160] Rivals, who did not incur the high fixed costs of creating that knowledge, would be able to free-ride on innovators and imitate their products at a much lower cost (the reverse engineering plus manufacturing costs). Knowing this inventors will fail to optimally invest in knowledge goods.

Finally, a crucial feature of investment in R&D is great uncertainty about the likelihood of success of any given research project. Absent some form of insurance against failure,[161] the market will tend to discriminate against high-risk, high-variance projects.[162] In addition, some types of research findings are particularly welfare-enhancing in that they drastically reduce the uncertainty of future research projects.[163] Think, for example, of the discovery of the mechanism of human-immunodeficiency virus (HIV) infection. Understanding the nature of the HIV virus itself as a retrovirus, that is, a virus that starts as ribonucleic acid (RNA), transforms itself into deoxyribonucleic acid (DNA), and then inserts itself into the genome of the host cell, lowered the number of research avenues into HIV therapies and increased the probability of success of each one of them—thus lowering overall uncertainty. Indeed, current successful HIV therapies are still in large part based on the knowledge that HIV is a retrovirus.[164] This type of uncertainty-reducing research will generate large spillovers—i.e. positive societal benefits that won't be fully appropriated by the inventing firm. When

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160 As a corollary, in a competitive market economy, the non-rivalrous and non-excludability of information will also push firms to "vertically integrate," that is to carry out both R&D and manufacturing in-house. This is because of what Arrow termed the "information paradox:" in order to negotiate a manufacturing agreement (or a development agreement) with a second firm, the firm that discovered the information would need to share that information with the second firm, so that the second firm could assess its value. But when the information is disclosed the second firm no longer has an incentive to negotiate for access to it.

161 Arrow, note ____, at ____.

162 Arrow, note ___, at 616 ("By the very definition of information, invention must be a risky process, in that the output (information obtained) can never be predicted perfectly from the inputs.").

163 Richard Nelson made a similar point about all basic scientific research and its uncertainty-reducing relationship with commercial inventions. ("In the activity of invention, as in most goal-directed activities, the actor has a number of alternative paths among which he must choose. The greater his knowledge of the relevant fields, the more likely he will be eventually to find a satisfactory path, and the fewer the expected number of tried alternatives before a satisfactory one is found. Thus, the greater the underlying knowledge, the lower the expected cost of making any particular invention.") at 300 Note that these kind of discoveries can also be conceptualized as producing large spillovers that cannot be appropriated by the existing legal regime. R. Polk Wagner has called this type of information "Type III" information or "open" information, available for
widespread use, as an inherent consequence of the creation of the underlying core innovation.

164 The main line of defense against HIV infection is therapies that inhibit the functioning of the proteins that convert RNA into DNA (reverse-transcriptase inhibitors). *, . .,* Eric J. Arts & Daria J. Hazuda, *HI -1 A D*, 2 COLD SPRING HARB. PERSPECT. MED. 1, 6 (2012) (noting that the twelve therapies that target HIV reverse transcription "account for nearly half of all approved antiretroviral drugs").

creating knowledge, and thus dispelling uncertainty, is costly and has high spillover effects, firms will tend to wait for competitors to make the initial investment and then use the resulting knowledge. In turn, , this will lead to underinvestment in uncertainty-reducing research.

Nontraditional team research is a special case of the underproduction of knowledge goods outlined above, but one in which the underproduction problem is severely exacerbated. The results of my empirical research help us see why this is the case for each of the three characteristics of knowledge goods—but in particular for the appropriability and uncertainty problems. Indivisibility is an important general problem for many team projects, which tend to require larger investments in infrastructure and basic research tools than those tackled by solo inventors. But the appropriability and uncertainty problems are worsened in the context of nontraditional teams.[165]

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A hallmark of nontraditional team research is its particularly large fixed costs of assembly. As my interviews reveal in the context of the Oncofertility consortium, there were social barriers (entrenched practice styles and different research priorities) that prevented the two communities of oncologists and reproductive endocrinologists from working together on fertility preservation despite their complementary knowledge base and skill sets. These observations are consistent with the theoretical and empirical literature on knowledge networks and structural holes. The two communities of oncologists and reproductive endocrinologists can be visualized as two clusters of dense social connections in the knowledge map, divided by a structural hole that prevented the free flow of information between them. They are also consistent with historical studies of innovation documenting "innovative delays" due to the inaccessibility of complementary information housed in non-interacting (or infrequently-interacting) communities.[166] Other empirical studies of inter-firm collaboration also support the existence of high up-front costs for team assembly when working across institutional or firm boundaries. For example, in a study of research joint ventures (RJVs) between firms, Röller Lars-Hendrik, Ralph Siebert and Mihkel M. Tombak found that "the more RJVs in which a particular firm is involved, the more likely it will be to join additional RJVs, i.e., the returns to RJVs are increasing."[167] The authors hypothesized that this increasing returns to RJVs were "suggestive of some organisational infrastructure or organisational learning required for RJVs (i.e., some upfront costs). Once some of the initial

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[165] Appropriability concerns are heightened for any collaborative effort. *, . .,* K. Laursen & A.J. Salter, *: A ,* , RES. POL. 867, 876 (2014) (finding that "an overly strong emphasis on appropriability may be associated with reduced efforts to draw in knowledge from many different external actors in formal collaborations for innovation.").

[166] Pedraza-Fariña, note ___ at ___ (collecting studies)

[167] Röller Lars-Hendrik, Ralph Siebert and Mihkel M. Tombak, *F F (D N F) J ?* 117 ECON J. 1122, (2007).

hurdles are past then participating in additional RJVs may become easier."[168] Taken together with the findings of my qualitative case study, available data shows that bringing teams together across technical boundaries will involve unique fixed costs, including overcoming communication barriers arising from different ways of conceptualizing a problem in participating communities, overcoming entrenched practice styles (or ways of prioritizing, organizing, and carrying out work), and reaching agreement on differing research priorities.[169]

Second, non-traditional team research is likely to generate spillovers that cannot be appropriated by any of the collaborating members, that are unique to boundary-crossing collaborations, and that are particularly socially valuable. This aggravates the appropriability problems created by the large fixed costs of assembling non-traditional teams. I will consider the impact on appropriability of the three type of spillovers I identified in my qualitative research, in turn: (1) problem finding; (2) new social networks; (3) reducing uncertainty at the intersection of multiple fields. Nontraditional teams, if successful, are likely to that were unexpected at the beginning of the collaboration. Two important features of this type of problem-finding are worth emphasizing: first, it is very likely that the discovery of new problems or research areas at the intersection of multiple fields would be significantly delayed the assembly of the non-traditional team. This is because awareness that there is a new problem to be solved often requires regular interaction among members in the different communities—not just access to published information from different fields. For example, in the oncofertility context, realizing that rodent and monkey follicles behaved differently and that this difference was clinically significant, required the sustained interaction of researchers working with mouse and monkey ovaries—even though these researchers were generally aware of each others' work and published papers. In this sense, the discovery of new problems is a unique social benefit of non-traditional team assembly. Second, the discovery of new problems or research areas at the intersection of multiple fields is closely associated with paradigm-shifting research.[170] For this reason, spillovers resulting from non-traditional team research are likely to be particularly socially significant. The original team members are likely to appropriate only a small portion of the social benefits generated by the discovered problem: finding a new research question is likely to open up

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[168] *I* . at ___>

[169] Part ___ (reporting on original empirical research on team formation). , Pedraza-Fariña, note ___, at ___. Empirical studies and models of collaboration in innovation are also suggestive of this result. , . ., Lars-Hendrik Röller, Ralph Siebert, & Mihkel M. Tombak, *F F (F)* RJVS, 117 ECON. J. 1122, 1141 (2007); Belderbos, R., Faems, D., Leten, B., & Van Looy, B., *A I F F : E E F* , 27 J. PROD. INNOV. MANAGEMENT 869 (2010) (finding that most firms underinvest in "explorative" research (i.e. research into new technology domains) but that collaboration both increases firms' investment into new technology domains and decreases firms' financial performance likely due to very high coordination costs).

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many research projects in multiple fields the rewards of which won't be captured by the original team members.

The creation of new social networks is also a direct by-product of non-traditional team research. In successful teams, such as the oncofertility consortium, new and stronger social bonds form between team members. From these new relationships among team members, a new set of relationships and collaborative research ventures is likely to emerge, as each individual team member brings his or her own pre-existing network to bear on new problems. And articulating new research questions at the intersection of multiple fields is also likely to bring together people from previously non-interacting networks. This is in fact what happened in the oncofertility context, as the networks of cryobiologists and reproductive biologists began to merge around the question of egg and tissue freezing.[171] There are clear social benefits to creating new networks around the solution of a novel research question—the most direct one being increased lines of research at the new intersection. But as was the case with problem finding, non-traditional team members will not be able to appropriate the full benefits of the new social connections sparked by their research. Finally, because much of collaborative R&D that spans technological boundaries is carried out in early stage, exploratory research, it will generate basic knowledge regarding the feasibility and productivity of research at the intersection of multiple fields. In the case of the Oncofertility consortium This is precisely the type of uncertainty-reducing basic research described above that is likely to be underproduced by the market.[172]

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Although the creation of any new knowledge is inherently uncertain, the type of research that is most often carried out by non-traditional teams is especially so. The case study of the Oncofertility Consortium introduces two features of research in non-traditional teams that are likely generalizable to other teams that similarly bring together communities of practice separated by structural holes: (1) higher frequency of unexpected problems and roadblocks than in "ordinary [team] science"; (2) predominance of exploratory over exploitative research. As its name indicates, exploratory research entails the exploration of new possibilities and new technical frontiers—most of basic research is exploratory in nature. In contrast, exploitation entails refining, optimizing, and scaling up existing knowledge.[173]

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172 Robert D. Atkinson, *E &E ,* , 32 J. TECHNOL TRANSFER 617, 626 (2007) (explaining that "most collaborative research, whether in partnership with a university, national laboratory, or industry consortium, is more basic and exploratory than research typically conducted by a single company.").

173 *, . .,* James G. March, *E E O L* , 2 ORG. SCI. (1991); Anil Gupta & Ken Smith, *I B E E* , 49 ACAD. MGMT. J. 693 (2006).

Technological innovation, of course, requires both. But theories of organizational learning predict that the balance between exploration and exploitation will tend to systematically favor exploitation—even though this leads to a suboptimal outcome (from an efficiency standpoint).[174] Returns from exploitation tend to be more certain, with shorter time horizons, and with less diffuse effects than those from exploration.[175] Organizations that focus on exploitation, thus channeling their energies to improving their competence at existing procedures, see increasing returns to experience in a short-term horizon. The more an organization improves its competence with existing procedures, the less attractive experimenting with alternatives becomes. As James March put it: "Reason inhibits foolishness; learning and imitation inhibit experimentation."[176]

2. Underproduction in Open Innovation Models

Intellectual property scholars who study open innovation and knowledge commons challenge several of the assumptions made in standard economic models as providing an inadequate description of real world incentives for and constraints to innovation. For example, Frischmann, Madison and Strandburg note how "free riding does not necessarily reduce incentives to invest and does not inevitably lead to a social dilemma. Reality is considerably more complex than the free rider allegory suggests, and there is no good reason for systematically marginalizing the many situations in which free riding does not reduce incentives to invest."[177] Through case studies of different innovation environments, several scholars have described how innovation can take place, and even flourish, in innovation communities that make their discoveries freely available to the public. These findings fly on the face of predictions made by economic models that focus on incomplete appropriability as a barrier to innovation. As Eric Von Hippel put it "it seems to make no sense that innovators would intentionally give away information for free that they had invested money to develop."[178] Yet, they appear to do so in several different contexts and with surprising regularity. For example, Von Hippel describes how user communities freely reveal their product improvements to each other and to the public at large.[179] And multiple studies of open source software developers trace the development of a social norm of open sharing in communities of coders (or hacker communities) to the research culture of 1960s and 1970s academic and corporate laboratories.[180]

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178 ERIC VON HIPPEL, DEMOCRATIZING INNOVATION 80 (2006)

179 *I . 78* (von Hippel defines "free revealing" as "all intellectual property rights to that information are voluntarily given up by that innovator and all parties are given equal access to it—the information becomes a public good.")

180 Von Hippel, note ___, at 97 ("Much of the software of the 1960s and the 1970s was developed in academic and corporate laboratories by scientists and engineers. These individuals found it a normal part of their research culture to freely give and exchange software they had written, to modify and build on one another's software, and to freely share

Other studies show how informal social norms can often substitute for intellectual property protection by tracking intellectual property norms themselves. For example, Oliar and Sprigman describe how communities of stand up comedians developed their own norms of ownership, including a norm "against publicly performing another stand-up's joke or bit"[181] which preserves incentives for joke creation without recourse to formal intellectual property law. Similarly, Fauchart and Von Hippel describe how a system of implicit social norms, analogous to intellectual property protection, has evolved among accomplished French chefs to discourage exact copying of publicly available recipes and to encourage proper recipe attribution.[182]

What all of these studies have in common is the description of a rich array of informal social norms and informal organizational structures not backed by legal remedies and consequences, that serve as an alternative incentive structure to markets to foster innovation. In these communities, innovation can be sustained without private property rights (or at least with more limited private property rights) because other, non-market incentives can take their place. All informal norms described—free revealing, reciprocity, banning public performance of other's work—however, are generally positively correlated with innovation. This highlights one important underlying assumption behind some of these projects: social norms are conceptualized as a substitute for governmental intervention in innovation markets.[183] Most case studies do not explore cases in which social norms are harmful to the production of certain types of socially beneficial innovation.[184] And, as I emphasized in Part I, case studies on open-innovation communities focus almost exclusively on the public availability of information created by these communities (or whether a commons is "open" to the public) as the key ingredient for sustained creativity and innovation. Few studies consider the impact on the pace and direction of innovation of the architecture of knowledge distribution.

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their modifications. This communal behavior became a central feature of "hacker culture.""). Von Hippel's definition of "innovator communities" is very similar to mine. Von Hippel defines innovation communities as "meaning nodes consisting of individuals or firms interconnected by information transfer links which may involve face-to-face, electronic, or other communication. These can, but need not, exist within the boundaries of a membership group. They often do, but need not, incorporate the qualities of communities for participants, where "communities" is defined as meaning "networks of interpersonal ties that provide sociability, support, information, a sense of belonging, and social identity"")

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182 Emmanuelle Fauchart and Eric von Hippel, *N - :*
F , http://papers.ssrn.com/sol3/papers.cfm?abstract_id=881781.

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184 One important exception in this trend are recent studies by Von Hippel, Strandburg, Frischmann and Madison that focus on the lack of social norms to widely diffuse innovations in user innovator communities – and their negative impact on the potential social welfare that could be derived from user innovations. [Cite work on user innovation and work diffusion]

My case for the underproduction of non-traditional team research is not based on stylized notions of how a hypothetical team would behave. In this sense, my study is firmly based in this research tradition that seeks to describe how real world communities confront innovation dilemmas. The case for the underproduction of non-traditional team research, however, holds both under standard assumptions made in economic models of innovation, and also when considering how teams work in the real world. In the case of non-traditional teams, informal norms and institutional structures act as a barrier to innovation, and contribute, rather than alleviate, a market failure in the production of non-traditional teams. It is precisely the informal norms developed in the two communities of oncologists and endocrinologists that the flow of knowledge necessary to solve complex problems among communities of practice by a structural hole between the communities. Specifically, as I detailed in Part II, the different research priorities and practice styles of the two communities prevented the framing of "oncofertility" as a research problem worth addressing. But social norms played a dual role in the case of the oncofertility consortium. Although they prevented the assembly of a team at the intersection of oncology and endocrinology, social norms of open data-sharing were also crucial in maintaining collaboration once the oncofertility consortium was established. The frequent, open sharing of data among team members with different research backgrounds in an atmosphere of trust created a virtuous cycle that motivated more data sharing and an increased commitment to the team project.

My research therefore suggests that policies aimed at correcting the underproduction of boundary-crossing innovation should focus on team rather than team . In other words, remedying this market failure may require only policies that serve as a temporary scaffold connecting the distant but complementary knowledge networks. Once social relationships develop among team members, intrinsic motivation may be sufficient to maintain the collaboration. In the next Part, I explore policy solutions to the underproduction of non-traditional teams, emphasizing how current policy levers to incentivize innovation more generally, such as patents and grants, paradoxically discourage the assembly of non-traditional teams.

III. SCAFFOLDING INNOVATION (OR HOW TO ASSEMBLE NON-TRADITIONAL TEAMS)

In the previous section, I made the case that non-traditional team research will be severely underproduced both under traditional and commons models of innovation. Correcting this underproduction should be a top priority for policy makers, given the important and unique social benefits that emerge from this type of research. Nevertheless, current innovation levers—in particular patents and grants—exacerbate, rather than correct, this underproduction problem.

Below, I address why patents and grants distort the innovation process away from non-traditional team research and towards types of innovation that are often less socially valuable. Grants can and should be reformulated to encourage research in non-traditional teams. In the final analysis, however, patents turn out to be an inadequate policy lever to incentivize non-traditional team formation and research. An important implication of this insight is that legal scholarship and policy should broaden its focus "beyond intellectual property"[185] to study how additional policy levers can mitigate the patent system's distortionary effects.

In the case of non-traditional teams, my empirical evidence indicates that policy interventions should be tailored to provide an initial, and temporary, "scaffold" across complementary communities of practice. Intrinsic motivation provided by working across boundaries may be sufficient to maintain productive non-traditional team research once barriers to assembly are eliminated. Thus, innovation scaffolds work as a form of "temporary law"[186] that nudges communities with potentially complementary and/or synergistic information and assets to work collaboratively on complex social problems neither community is likely to solve alone. I conclude this section by exploring how non-IP incentives, including grants, prizes and taxes can be reformulated to include a scaffolding component for non-traditional teams.

A. E I I

1. Patents

Patents do not directly discourage non-traditional team formation. Rather, patents influence a firm's decision among research projects, nudging them to favor relatively short-term, high appropriability projects. But most non-traditional team projects are likely to have the exact opposite features: they are long-term, low-appropriability projects. As a consequence, patents often exacerbate the problem of non-traditional team research. In addition, patents take the innovation possibilities of a firm—its technological area of focus, its research culture, its embedded routines—as a given. When fostering innovation requires the reorganization of existing social structures, patents will be ill-suited to the task.[187] I examine each one of these effects below.

Patents have long been hypothesized to have distortionary effects on the types of research a firm will choose to undertake. Some of these effects increase social welfare, and are an intended feature of the patent system. After all, the whole idea of a patent system is to encourage firms to pursue projects they would otherwise find too costly. For example, the obviousness doctrine's widely accepted purpose is to prevent patent grants on variations of existing inventions that would have arisen through market competition

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186 Tom Ginsburg, Jonathan Masur & Richard H. McAdams, Libertarian Paternalism, *D* , *L* , 81 U. CHI. L. REV. 291 (2014)

187 , . ., J.S. Metcalfe, *E E* , 104 ECON. J. 931 (1994) ("How much the behavioural firm spends on innovation is reflected in its routines, including those for determining its profit mark-up on costs and the proportion of sales revenue that it allocates to R&D and other innovative activities.").

alone.[188] The obviousness doctrine thus encourages firms to undertake riskier projects than they would have undertaken absent patent protection.[189] But other, largely unintended, features of patent law affect firms' choices of research projects in ways that are often socially detrimental. For example, Eric Budish, Benjamin Roin, and Heidi Williams provide empirical evidence that the structure of the patent system encourages private firms to "differentially - "—defined as "technologies with long time lags between the initial spark of an idea and the availability of a commercially viable product."[190] These authors found that firms invest more in late-stage cancer drugs than in early-stage or cancer prevention drugs because the former have shorter clinical trials and can thus be brought to market earlier, increasing a firm's monopoly profits.[191] The social costs of this distortion are very large: Budish, Roin and Williams estimate the net present value of the life years lost by this distortion to be $2.2 trillion. [192]

Non-traditional team research, and in particular the type of research carried out when a non-traditional team is initially assembled, tends to have a long-term horizon. This is likely the case both regarding the amount of time needed to have a patentable invention, to take that invention to market once a patent is granted. Taking Budish, Roin and William's definition of what constitutes long-term research, it is likely that there will be a longer time span between the initial "spark" or creative idea discovered in a non-traditional team to its commercialization, than would be the case in a homogenous team working in a well-known technological area. Ideas at the intersection of multiple communities tend to be more uncertain, and thus more likely to run into more scientific roadblocks in their development than well-tested, incremental improvements in a well-known field.[193] And even if non-traditional research does not run into scientific roadblocks any more frequently than "traditional" research, new research at the intersection of communities of practice that do not routinely interact with each other will likely be exploratory. In other words, even if immediately successful, research at the intersection of multiple fields will often need time to develop research protocols, reagents, facilities, etc. to translate (or exploit) its findings into a commercial product. Importantly, this is the case regardless whether the innovation takes place in a corporate environment (e.g. a pharmaceutical or biotechnology company) or a public research institution (such as a university).

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188 Robert Merges, , 7 BERKELEY TECH. L. J. 1, 20 (1992) ("[A]ssuming the amount of potential R&D investment is fixed, when patents are introduced there will be some displacement from the low-risk research that would have been pursued absent patents. On the other hand, if the social rate of return from the higher-risk projects is greaterand there is reason to believe it will be-this displacement is warranted.")

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190 Eric Budish, Benjamin Roin & Heidi Williams, *D F L - ? E C C* , 105 AM. ECON. REV. 2044, 2045 (2015) (emphasis added).

191 *I* . at 2046 ("[C]orporate short-termism and fixed patent terms reinforce each other in distorting private research dollars away from long-term investments.")

192 *I* . at 2080

193 Part ___ .

Take the research conducted in the Oncofertility consortium. Researchers were forced to modify their approaches to maturing follicles multiple times, in light of findings that emerged from the interaction among scientists with different disciplinary perspectives. For example, in Part II, I documented the insight that emerged out of the focused interaction between researchers working in mouse and monkey models. These researchers realized that monkey follicles reacted differently to maturation signals than mouse follicles: a portion of monkey follicles remained unresponsive ("they just sat there"[194]) while this was never observed in mouse follicles. Because monkey follicles are thought to behave more like human follicles than mouse follicles, the interaction revealed a roadblock to translating mouse research to humans.

Members of the Oncofertility consortium are also inventors in several patent applications, including several for the important "biomaterial matrix" technology to culture human follicles—and potentially other organs— (. . to grow human eggs) developed through the collaboration between engineering and reproductive endocrinology researchers.[195] But efforts to find a company that would scale up this technology and bring it to market have thus far proved fruitless—in large part, Oncofertility researchers hypothesize, because of the long-term horizon likely required to turn this invention in a nascent field into a commercial product. Interestingly, inventors on Oncofertility patents told me that the main reason why they obtained patents for their research was attributional: to get proper credit for their intellectual contributions. The prospect of obtaining a patent did not play an role in incentivizing individual scientists to join the non-traditional team.[196]

One of the key functions of patents under traditional models of innovation is to diminish free-riding by allowing inventors to appropriate the social benefits of their inventions. But, as Amy Kapczinsky and Talha Syed have pointed out, there are some types of inventions whose social benefits are particularly hard to appropriate, even with patent protection.[197] Thus, patents "fix" the appropriability problem for some inventions, but not for others—there is a "continuum of excludability."[198] This, in turn, distorts incentives for companies to invest in those innovations whose social benefits are easily appropriable through patent law. Kenneth Arrow recognized this potential distortion when he suggested a likely bias against major inventions because an inventor is likely to obtain "the entire realized social benefit of moderately cost reducing inventions but not of more radical inventions."[199]

The continuum of excludability represents a particular problem for nontraditional team assembly. In Part II, I described the types of spillovers

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195 , . ., Hydrogel compositions, WO 2008098109 A2.

196 Of course, business or managerial units in corporations, or even technology transfer offices in universities, may use patents in different ways.

197 Amy Kapczynski & Talha Syed, *C E L* , Yale L. J. (2013)

198 Kapczynski & Syed, note ___, at ___.

199 Arrow, note ____, at ____.

generated by boundary spanning team research, using the Oncofertility Consortium as a case study: (a) problem finding; (b) creating new social networks; (c) reducing uncertainty of doing research at the new intersection. Because these spillovers are particularly socially significant, the gap between private and social benefits is likely to be quite large in nontraditional team research. Imagine, for example, that a pharmaceutical company is considering two potential research paths. It could focus on developing an improved version of its blockbuster cholesterol-lowering statin drug. The improved version would seek to diminish muscle pain—an important side effect of the statin drug. Or, it could partner with a computer modeling company to develop new (non-invasive) imaging techniques to identify and diagnose mental diseases such as schizophrenia and Alzheimers. In turn, these imaging techniques could aid in mapping the different brain signatures of mental diseases, likely giving rise to new fundamental questions in the field (. . problem finding). They could also improve our understanding of how to use mathematical computer modeling in the neuroscience field (. . reducing uncertainty of research at the intersection of computer science and neuroscience). Finally, if successful, the initial collaboration between computer scientists and neuroscientists is likely to draw more researchers from these two disciplines to this intersection (. . creating new social networks). The gains derived from the collaboration are almost certainly higher than those obtained from an improved statin drug.[200] But many of these gains are hard to appropriate by the first set of collaborators. For example, a successful patent and product in this new field will lower the risk to subsequent entrants of doing research at this intersection, and may in fact foster more neuroscience-computer science partnerships, but this is not a benefit that can be (easily) captured by the initial inventors. The benefit of discovering new problems for future research accrues to everyone in the new field, unless the firm can keep those new problems secret. As new entrants join the field or as researchers begin using the new imaging technique, however, they will likely discover the same new problems making long-term secrecy unlikely.[201] At any rate, the outcomes of the new patented imaging technique are harder to appropriate than those of a new patented drug. Because of this discrepancy, the net private benefits obtained from selling the new patented statin drug may well be higher than those obtained from selling the new imaging technique—encouraging a firm to prioritize research into the new drug.[202]

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200 *, . .,* Katherine Srandburg and Michael Meurer, *C* , LEWIS & CLARK L. REV. ("[T]he greater the technical advance, the more the social value associated with that advance exceeds the private value. This assumption reflects the reasonable notion that bigger inventive steps are likely to lead to more extensive and broader opportunities for follow-on innovation and, in particular, that they are more likely to lead to a broader and more extensive set of improvements that will not be made by the original inventor.")

201 [Note that here the company can choose not to license the invention].

202 *, . .,* Glynn Lunney, *E-C* , Mich. Tel Comm L. Rev. (arguing that free riding can decrease the private rents available from high-creativity projects, thus drawing investment to lower-creativity projects even if the high-creativity projects have higher social value.)

In my analysis of the appropriability problem, I have described a firm's innovation process as a series of choices among research projects. This is a common, and useful, depiction of firms' behavior in models of innovation that try to estimate the effects of different patent doctrines on research decisions made by research firms. The same model can be applied to decisions made by an individual researcher or by the principal investigator in a laboratory in a public research setting. Of course, in order to choose among alternative research paths, these paths must be "visible" to firms or individual researchers. In the context of non-traditional team research, this means that the option of collaborating with research partners from different communities of practice must be readily available to the firm as part of its universe of potential research trajectories. This will typically be the case when a firm has a particular problem to be solved that calls for a specific complementary expertise,[203] and when the fields at issue have some detrimental. In fact, many research scientists themselves have recently written pointed critiques of the National Institutes of Health grant system, and called for its immediate reform. All of these critiques have two points in common. First, the current structure of the grant system encourages short-termism and discourages risk-taking and creativity. Second, current evaluation procedures are biased against non-traditional teams. My original research on the Oncofertility consortium similarly found that the R01 grants that make up the majority of NIH grant applications made it very difficult to obtain funding for research that crossed traditional disciplinary boundaries (in particular, endocrinology and engineering). The reasons that I uncovered to explain this difficulty—competition and non-coordination among NIH institutes—however, have not been widely discussed in commentary by scientific researchers and other policy analysts.

Several prominent scientists have criticized the NIH grant structure for encouraging short-term thinking and discouraging risk-taking and creativity. Two features of the NIH grant system are blamed for this undesired outcome: the insistence on the part of NIH review teams on ever-increasing amounts of "preliminary" data, and an increasing focus on demonstrating the feasibility of the project (rather than a focus on how creative, original, or potentially pathbreaking a project has the potential to be). In the words of NIH Principal Investigator, Ronald Germain, many investigators see [the NIH grant process] as "a stultifying, regimented process in which form often counts for more than content and in which any proposal lacking substantial evidence of already having been largely accomplished is unlikely to be supported."[207] Four prominent scientists, Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus likewise criticize the grant system for favoring "those who can guarantee results rather than those with potentially path-breaking ideas that, by definition, cannot promise success."[208] With such a focus on preliminary data and predictability, these scientists argue, scientific progress is slowed down and revolutionary findings deferred.[209]

As I described in more detail in Part ___, one of the hallmarks of non-traditional team research is its uncertainty when compared to research carried out by established homogenous teams. Indeed, Alberts, Kirschner, Tilghman and Varmus explicitly blamed the NIH grant process and its focus on predictability for discouraging both young and seasoned investigators from "posing new questions and inventing new approaches"[210] and "explor[ing] new fields"[211]—all elements that are required to bridge structural

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[207] Ronald N. Germain, *H NIH-F B E*, 161 CELL 1485, 1485 (2015).

[208] Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus, , 111 PNAS 5773 (2014).

[209] Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus, , 111 PNAS 5773 (2014).

[210] *I* . at

[211] *I* . at

holes between scientific communities. Instead, grants incentivized researchers to "stick to their tried-and-true formulas for success."[212]

The critiques directed at the NIH grant system also more specifically described how current grant review procedures discourage collaborations across scientific disciplines. For example, Alberts, Kirschner, Tilghman, and Varmus described a research field's tendency to become "parochial."[213] They warned that when review bodies (in charge of evaluating grant proposals) become "too insular, they risk becoming special interest groups for their subfield and may fail to encourage support of the most imaginative science."[214] This is how Oncofertility Consortium members described their experience trying to obtain and R01 grant—funding was complicated by the fact that their research did not fit neatly into any one well-developed and well-recognized area of research, but rather, fell at the intersection of several areas.[215] Other research has also found that the NIH panel evaluation, which traditionally aggregates experts with particular knowledge boundaries is ill-suited to evaluate multi-disciplinary research.

Interviews with Oncofertility Consortium members also revealed a second institutional barrier to non-traditional team research: to the extent that funding for research that crosses scientific fields requires coordination among different NIH institutes, such coordination proved arduous and often unproductive.[216] As grant supervisors with little experience in the disciplines represented in the grant sought to enforce the goals and research plans set forth in the original grant proposal, researchers struggled to retain crucial flexibility needed to make advances an uncertain new field.[217] And NIH institutes often had coordination problems, competing with each other for control of the Roadmap grant.[218]

B. I I C

If the two major policy levers to foster innovation—patents and grants—in fact discourage non-traditional team research, what policy options are available to regulators to adequately incentivize it? My research suggests that what is really hard about non-traditional team research is its assembly—this is what chemists call "the rate-limiting step." A key reason why external incentives are needed to bring together communities across structural holes is that informal norms developed in these non-interacting communities, together with the current incentive structure provided by patents and grants, push against closing structural holes. Hence the title of this Article "Scaffolding Innovation" seeks to conjure up a key function of policy interventions: to temporarily bring together non-interacting communities across a structural hole. Of course, there are many reasons why maintaining

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[212] *I* . at ____.
[213] *I* . at ____.
[214] *I* . at ____.
[215] Part ___.
[216] *I* . at _____.
[217] *I* . at _____.
[218] *I* . at _____.

collaboration can also be difficult.[219] But my research, along with data from industry collaborations, provides good reasons to conclude that companies or individuals who successfully collaborate with others outside their field are more likely to continue doing so in the future without additional external incentives. For example, in a study of firm joint ventures, Lars-Hendrik Röller, Ralph Siebert and Mihkel M. Tombak find that "the more [Research Joint Ventures] RJVs in which a particular firm is involved, the more likely it will be to join additional RJVs."[220] The authors interpret this increasing return to RJVs as "suggestive of some organisational infrastructure or organisational learning required for RJVs (i.e., some upfront costs)."[221] Many research joint ventures are set up among firms with complementary knowledge bases and techniques—and some (but certainly not all) of these alliances likely bridge structural holes across industries, making these findings relevant to the formation of non-traditional teams across firm boundaries.[222]

My research provides an intriguing explanation for the continued willingness to continue collaborating outside one's field of specialty once an initial collaboration has been estalished: the intrinsically motivating effect of working across disciplinary boundaries. These findings should be interpreted in conjunction with other elements that likely made the Oncofertility Consortium collaboration successful. Key among them is the fact that the core Oncofertility Consortium members belonged to a pre-existing social network. All of them knew each other, and knew Dr. Teresa Woodruff, by virtue of having participated in NIH focus group meetings about the ovary. Other research on collaborations and collaboration networks similarly emphasizes the important role of pre-existing relationships and emotional bonds among group members.[223] These are likely to be particularly important elements in non-traditional team research as they work to offset the potentially disruptive forces generated by researchers coming from different technical backgrounds with different research priorities and interests.

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219 [Note how maintaining collaboration in non-traditional teams, however, may in fact be easier than in traditional teams where free-riding is likely more of a problem.]

220 Röller, Siebert & Tombak, note ___, at ___.

221 *I* . at ___.

222 discussion Part ___. My case study dealt with collaborations among basic scientists from different disciplines, and among basic and clinical researchers that took place largely in a University setting. But the underproduction of non-traditional teams is not limited to University research. [Add a section/explanation on how to extend and/or apply framework to industry context]

223 *, . .,* Richard B. Freeman, Ina Ganguli, Raviv Murciano-Goroff, *I C* , THE CHANGING FRONTIER: RETHINKING SCIENCE AND INNOVATION POLICY 17, (Adam Jaffe & Benjamin Jones eds. 2015) ("One striking finding is that nearly all geographically distant coauthors were once collocated. Typically these distant coauthors were previously collocated either as colleagues, as visitors or in an advisor-student relationship."); Katherine Strandburg, Brett Frischmann & Can Cui, *D C N C D C N K C ,* Governing Knowledge Commons (emphasizing the importance of pre-existing social networks in the successful performance of the Urea Cycle Disorders Consortium); John N. Parker & Edward Hackett, *H H M C M* , 77 Am. Sociol. Rev. 21 (2012).

This should be heartening: overcoming barriers to working across disciplinary boundaries may require a short-lived catalyst. But how can policy instruments work as scaffolds for non-traditional teams? A full exploration of different policy options and their comparative strengths and weaknesses is impossible in the space of a single paper. In the remainder of this Article, I highlight three promising approaches to scaffolding innovation: (1) *N -* *G* (both for basic research and in the pre-competitive space); (2) *A* ; (3) *C* *C* *N -*

The Roadmap Grant Project was short lived: it funded nine consortia for a period of seven years (2005-2012).[224] Tethered to the "Common Fund"[225]—a discretionary pool of funds that each successive NIH Director can use to shape science policy during his/her tenure—the Roadmap Grant ended with Dr. Zerhouni's tenure.[226] Currently, there is no grant equivalent to the NIH Roadmap grant for Interdisciplinary Research. Although several existing NIH grants are designed to encourage collaboration, none of them target the formation of non-traditional teams. Rather, the current common fund initiatives, as well as other NIH initiatives to foster collaboration, are focused more extensively on big data collection and annotation—an important project that requires collaboration, but not the type of non-traditional team research I discuss in this article.[227] The hurdles present in big data analysis are not those of structural holes, but rather those of constructing a shared infrastructure for data analysis and coordinating its collection. Indeed, many of these projects "involve application of known methods to an important problem."[228]

Therefore, one possibility for creating innovation scaffolds is to reintroduce a non-traditional team grant mechanism.[229] Such a mechanism would solicit proposals from principal investigators from any disciplinary background to research intractable problems whose solution requires the insights and joint work of multiple technological domains. The grant could also be expanded to include proposals from industry or industry-academia initiatives (public-private partnerships) that specifically engage multiple research communities and disciplines.[230] One important legacy of the Roadmap Initiative is the NIH Office of Public-Private Partnerships. As Liza Vertisky notes, the mission of this Office is to "create partnership opportunities and make them attractive to private partners in the hope of encouraging voluntary private sector shifts towards collaborative

224 https://commonfund.nih.gov/Interdisciplinary

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228 Bruce Alberts, Marc W. Kirschner, Shirley Tilghman, and Harold Varmus, , 111 PNAS 5773 (2014).

229 [Describe how the original mechanism brought together multiple types of grants under the coordinated supervision of several NIH institutes.]

230 *, . .,* Liza S. Vertinsky, *, , -C C M I* , 48 U.C. DAVIS L. REV. 101 (2015).

innovation."[231] It would not require a major restructuring effort to encourage this Office to pay particular attention to facilitating the technology-spanning types of collaboration that I discuss in this article.

Designing such a grant, however, should address two important problems identified in my research. First, the Roadmap Grant sought to fund projects that "no single NIH institute could tackle alone." Rather than designate a single Institute to administer individual grants, the Roadmap put multiple NIH Institutes in charge of individual grants. This was an unfortunate mistake. Perhaps predictably, different NIH institutes competed with each other and vied to steer individual grants along their specific institute research goals, rather than serve as an effective coordinating mechanism.[232] Ironically, underlying the clash between NIH Institutes were the very same informal norms—divergent research priorities and entrenched practice styles—that crippled initial collaboration in oncofertility research. The result was thus to reproduce existing disciplinary divisions at an institutional level. To mitigate these difficulties, the NIH should create a stand-alone body tasked with coordinating the new Interdisciplinary Research Grants. A second important problem was the lack of flexibility to adjust team goals and procedures from the original grant proposal. This inflexible approach is out of step with the high-risk, uncertain research that the Interdisciplinary Research grants were meant to foster. Grant reviewers should allow some deviation from a team's original proposal—provided the overall subject matter of the research fits with the problem to be addressed by the team. Finally, many of the proposals to reform the NIH grant system to encourage risk-taking and the exploration of new fields would go a long way to ameliorating the distorting effects of grants on the assembly of non-traditional teams.

Another mechanism by which the Government may foster non-traditional team formation is through administrative regulation. In particular, in 2004 the Food and Drug Administration (FDA) launched the Critical Path Initiative to address "the recent slowdown, instead of the expected acceleration, in innovative medical therapies reaching patients."[233] Many of the problems identified by the FDA in its 2004 Report "Innovation Stagnation" can be reframed as problems building scaffolds between the basic science and clinical communities, on the one hand, and between multiple basic science communities, on the other. For example, the report notes:

> The product development problems we are seeing today can be addressed, in part, through an aggressive, collaborative effort to create a new generation of performance standards and predictive tools. The new tools will match and move forward new scientific innovations and will build on knowledge delivered by recent

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[232] , . ., Laura Pedraza-Fariña, *F C : A E C A* , BERKELEY TECH. L. J. (2015)

[233] FDA, INNOVATION OR STAGNATION: CHALLENGE AND OPPORTUNITY ON THE CRITICAL PATH TO NEW MEDICAL PRODUCTS iv (2004)

advances in science, such as bioinformatics, genomics, imaging technologies, and materials science.[234]

In other words, new product development will require the collaboration among different scientific communities (bioinformatics, genomics, imaging technologies, and materials science) with each other and with those scientists involved in clinical trials and product development. The Critical Path Initiative provides an opportunity for the FDA to work together with the NIH Office of Public-Private Partnerships to create an infrastructure for fostering such collaborations.

Finally, the government can use tax incentives to foster non-traditional team assembly. Tax incentives in the United States, however, and in contrast to those of other countries with intensive R&D industries, are generic—they enable firms to deduct research and development costs. Precisely because tax credits are generic, any uniform increase in tax subsidies is likely to lead to a dynamic misallocation of resources by oversubsidizing research into patentable low-hanging fruit and worsening the underinvestment in the assembly of non-traditional teams.[235] To correct this distortion, the U.S. could adopt a special type of tax credit requiring nontraditional collaboration between industries that specialize in different technical domains (a cross-technology tax credit). Many other countries currently have a collaborative tax credit available to industries, and the design of the U.S. cross-technology tax credit could begin by looking to these models for initial guidance. For example, Belgium, Denmark, Japan, and France provide tax credits for industries collaborating in the development of products with universities or research institutes (thus fostering clinical/industrial-basic research collaboration).[236] Quebec provides a tax credit for all companies collaborating with eligible university, research institutes, or research consortia.[237] Most of these tax credits focus on one particular type of scaffolding: that between basic science and clinical/industrial communities. A tax credit for joint ventures between industries in different technological environments is another possibility. This type of tax credit, however, will need to screen out collaborations among industries in similar technological domains that are market competitors. These industries may seek to collaborate not to create synergistic knowledge by combining two or more distant technological domains, but rather to consolidate market power and decrease competition.[238]

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[234] FDA, INNOVATION OR STAGNATION: CHALLENGE AND OPPORTUNITY ON THE CRITICAL PATH TO NEW MEDICAL PRODUCTS iv (2004)

[235] , . ., D.J. Wilson, *B N ? I - , O - - , A E &D C* , 91 REV. ECON. STAT. 431, (2009)

[236] , . ., Robert D. Atkinson, *E &E ,* , 32 J TECHNOL TRANSFER 617–628 (2007).

[237] *I .*

[238] , . ., John T. Scott, *N C A ,* ISSUES IN COMPETITION LAW AND POLICY 1297 (2008) (discussing how some research joint ventures can have anti-competitive effects when collaborators in similar industries, with similarly diversified internal research portfolios, simply pool their assets to reduce duplicative research).

IV. CONCLUSION