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A churn model of scientific knowledge value: Internet researchers as a knowledge value collective

Barry Bozeman*, Juan D. Rogers

School of Public Policy, Research Value Mapping Program, Georgia Institute of Technology, Atlanta, GA 30318-0345, USA

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Abstract

Determining the value of scientific and technical knowledge poses a great many problems. One of the most acute and widely recognized is that the value of knowledge shifts dramatically over time as new uses for the knowledge emerge. A related problem is that market-based valuation of knowledge is an inadequate index of certain types of scientific knowledge. We present an alternative framework for the value of scientific and technical knowledge, one based not on market pricing of information, but instead, on the intensity and range of uses of scientific knowledge. Our "churn" model of scientific knowledge value emphasizes the distinctive properties of scientific and technical knowledge and focuses on the social context of its production. In particular, we consider the value of scientific and technical knowledge in enhancing "knowledge value collectives", our term for the set of individuals who interact in the demand, production, technical evaluation, and application of scientific and technical knowledge. To illustrate the use of the churn model as an interpretive framework, we examine the recent history of the Internet and the churning knowledge use and transformation accompanying its emergence. The development of the knowledge brought together in the Internet shows us how little traditional disciplines and institutions help in explaining today's epoch-changing knowledge and technology innovations. We urge a focus on the social configurations producing knowledge value. Rather than counting discrete output, we argue that research evaluation is most helpful when its subject is the capacity of social configurations to produce new scientific and technical knowledge uses. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Knowledge value; Scientific knowledge; Internet innovation; Churn model

1. Introduction

In the social sciences, developments in the world of public affairs often require us to unpack theories and suppositions long stored. As a case in point, consider market-based theories of scientific knowledge and its value. As public policy-makers become more serious about evaluating the scientific work developed and supported by government funding, limitations of economic models of knowledge value are brought sharply into relief. So long as market-based concepts of scientific knowledge value were taken in the abstract, or used chiefly in theory building, limitations were not so apparent. But once employed as a framework for understanding and assessing actual cases of scientific knowledge creation and its use, the traditional economic models leave much to be desired. With their focus in discrete goods and transactions, monetized commodities and price-as-value, such theories fail to capture much of the reality of scientific work or the social uses of science's knowledge products.

Among US policy-makers, the Government Performance and Results Act (1993) (GPRA) in part

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* Corresponding author. Tel.: +1-404-894-0093;
fax: +1-404-385-0504.
E-mail address: barry.bozeman@pubpolicy.gatech.edu
(B. Bozeman).

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motivates the casting about for fresh ideas.[1] But GPRA is only the latest among several social and political trends (e.g. Byerly and Pielke, 1995; Guston and Keniston, 1994; Kleinmann, 1995) undercutting the tradition of self-governed science (Polanyi, 1962) and the conjoining of the free market and the "free market of ideas". Science evaluation and, generally, understanding of the socio-political context, has long labored under the limitations of neoclassical economic theories and market metaphors. Viewing science as a market for discrete science commodities distorts the value of knowledge and ensures an unrealistic conception of scientific work. We argue that market-based notions of scientific value often overlook aspects of value not easily reflected in pricing and pricing structures. The difficulties economic theorists have experienced making sense of the value of fundamental knowledge is not simply a reflection of the troublesome nature of public goods and externalities but, rather, a reflection a much deeper problem—an errant (or at least incomplete) theory of knowledge value. Economists are often among the first to admit that pricing efficiency sometimes says very little useful about the value of information.

Our objective is to develop a theory of knowledge value that comes closer to reflecting the multiplicity of uses of scientific knowledge, a theory that begins with the hard truth that knowledge value is not transitive among users. In our theory, the value of scientific knowledge is socially embedded in a collective of producers and users (many of whom play both roles). Scientific knowledge is developed through the transformation of extant knowledge into diverse new uses, uses that may have little or nothing in common with previous applications of knowledge. These new uses, in turn, enhance the reservoir of knowledge available for further transformation (into further uses which, in their turn, provide for new potential transformations). We use the term "churn model" for this use and transformation process because the notion of "churn" implies no particular direction (e.g. linear) and no imputation of scientific progress. The standard definition of churn, "a violent stirring; to shake or agitate with continued motion" (Webster's Unabridged Dictionary, 1979, p. 324) captures our notion of scientific knowledge quite well. A churn model of knowledge value is coincident with the radical changes in knowledge use (and thereby value) one witnesses in society. To extend the metaphor, scientific knowledge resembles the churning of cream into butter—the constituent elements are stirred until a qualitative change results. The qualitative change provides new uses of knowledge, not intrinsically better ones (as butter is not inherently superior to cream).

The churn model includes implications not only for knowledge value theory, but for evaluation theory. According to our model, the most suitable object of evaluation is not discrete knowledge units (if such things can be said to exist), or their market value, but the social configurations that enable the production of scientific knowledge. These social configurations, which we call "knowledge value communities", can be assessed in terms of their ability to provide scientific and technical capacity (as embodied in individual scientists taken together or separately) and, most important, their ability to provide new uses or applications of scientific knowledge.

In this paper, we elaborate the churn model and its antecedent concepts and assumptions. We illustrate a churn perspective by analyzing two very different cases: the history of the Internet's development and NSF/NASA Plant Research Network. This historical analysis of the knowledge creation and use characteristics of the Internet's development is based in part on two separate interview-based studies with converging conclusions (Rogers, 1996; Bozeman, 1997 in Roessner, 1997). The Plant Research Network case is based on a site visit case study by the authors. Finally, we examine implications of a churn model for research and knowledge evaluation.

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[1] The US Government Performance and Results Act (GPRA) requires most government agencies, including those providing for the nation's basic research, to give serious attention to evaluating impacts. One requirement is the submission to the Office of Management and Budget and the Congress of strategic plans and, ultimately, impact measures that will be used in performance-based budgeting reviews. The plans, the drafts of which were submitted to poor congressional reviews in October 1997, include a mission statement, goals tied to outcomes, and a description of the agency's plans for evaluating performance in connection with measurable goals. Beginning in fiscal year 1999, these processes become routine as agencies must submit an annual performance plan, one that is quantifiable, gives measurable goals, and includes quantitative performance indicators. Moreover, these plans and measures will be used in performance-based budgeting reviews and are expected to play a major role in the Office of Management and Budget's recommendations for new budget allocations to agencies.

1.1. Economic valuation of knowledge

In academic realms, ferment about the “new economics of science” (see Stephan, 1996 for an overview) challenges conventional assumptions about valuing scientific and technical activity. For many years, public deliberations about the value of science have been strongly influenced by economic reasoning. So long as traditional economic valuation of scientific and technical knowledge went unchallenged by practical application, it seemed adequate for providing a broad framework of understanding. When that broad framework began to be pressed into active duty, inadequacies quickly became apparent. The most important of these is that the rents one captures for scientific and technical knowledge often seem quite unrelated to anyone’s conception of the actual social and intellectual value of the knowledge. For years, this lack of correspondence between economic valuation any other metrics for assessing value (e.g. consensus, common sense, use patterns) was dismissed as owing to externalities, market failure or distortions. Now the valuing of scientific and technical knowledge pertains not only to pricing and ex ante allocation of resources by governments and other collective actors, but increasingly to the ex post evaluation of those investments. In many such cases, market value and prices levied for knowledge are obviously inadequate indices of value. For policy-makers, generally interested more in social value than in rents, the limitations of economic theories of knowledge value are becoming more obvious (e.g. US GAO, 1997; National Academy of Sciences, 1999).

Familiar theories of the political economy of science and technology remain quite useful in many of their traditional domains, but typically offer little guidance for explicit valuing of science. Thus, production function theories, intended originally for assessing the contribution of nations’ science and technology to economic growth (e.g. Solow, 1957; Griliches, 1979), fare poorly as models for more narrow-gauged evaluation. Similarly, elaborate public expenditure models, still useful as guides for allocating technical activity between public and private sectors (e.g. Johnson, 1972; Arrow, 1962; Alchian and Demsetz, 1972), help little in assessing allocation results.

The “new economics of science” suggests that old economics-based theories of knowledge value have limited application and propose new approaches. But the need is not so much for a new economics as a non-economics, an approach to valuing science that relies on something other than our ability to monetize. Following work by Callon (1992, 1994a,b, 1997) and co-workers (e.g. Liyanage, 1995; Rappa and Debackere, 1992; Elzen et al., 1996, and, especially, Crane, 1972), we argue the need for a more expansive concept of scientific and technical work and its impacts.

Practical research evaluation almost inevitably leads one to ponder the difficulties of measuring knowledge value. In too many cases, however, the search for false precision leads to monetary indices and away from the content of knowledge and its particular and highly differentiated uses. Many research evaluations have focused on the wrong thing (first-order output) and have looked in the wrong place (the scientific project). Often a project focus is misleading. The terms “R&D project” and “R&D program” fail to capture the inherent dynamism of the interchange between work in R&D laboratories and external influences and impacts of that work (Joly and Mangematin, 1996; Laredo and Mustar, 2000). In our case studies (Bozeman et al., 1998; Bozeman and Roessner, 1995; Rogers and Bozeman, 2001), we have found that many scientists do not conceptualize their work in terms of the funding source or the project account and, instead, view projects as chiefly a bureaucratic artifice. The building of artificial boundaries between the micro-world of scientists and engineers and the macro-world of commerce, education and sundry institutions using the work of scientists and engineers produces piecemeal theory when the need is for integrative theory (Vaughan, 1999). For those of us interested in actually evaluating impacts, these blinders lead to misplaced measures and dubious claims. As Latour (1983, p. 143) observes correctly, “. . . the very difference between the ‘inside’ and the ‘outside’, and the difference of scale between ‘micro’ and ‘macro’ levels, *is precisely what laboratories are built to destabilize or undo*” [emphasis ours].

1.2. Embedded value

The churn model of knowledge value assumes that economic currency is at best a surrogate for the inherent value of scientific knowledge. Once put to use, knowledge has demonstrable value. But that value typically has no transitive value and may not be amenable to economic indexing. The history of fundamental research shows that creating and deploying knowledge relates only obliquely to the creation of commodities. Yes, fundamental research can be priced, but price may be a less exact measure than repeated, broad-domain use. Economists cast this as market failure. In our judgment, the problem is much more fundamental. Valuing basic research fails not because of the economic properties of information, but because of its pre-economic properties. Knowledge is put to use, use confers value, economics hurries to catch up with that more fundamental evaluation-as-use and often fails to do so. There is little essential difference between a user community's valuation of knowledge about thermodynamics and the peasant village community's valuation of barter transactions in a village's embedded "economy": in both cases, traditional market measures give a dim picture of value.[2]

1.3. An alternative to prices: valuation-by-use

The purpose of our paper is to provide an alternative to traditional economic valuation of scientific knowledge. Our churn model of knowledge value is based on the *range and repetition of uses of scientific and technical knowledge*. Use is an explicit act of valuation on the part of the user. If scientific and technical knowledge is purchased at great expense, use indicates value; if scientific and technical knowledge costs nothing (in monetary terms) use is nonetheless, a direct imputation of value.

Ours is not a new economics approach. In a sense, it is "pre-economic" or embedded (Scott, 1976). We are concerned with the hedonic value that economists and others seek to monetize, not with the economic reflections of value. That value is inherent in use. Monetary units represent exchange value and serve well for uncomplicated exchange. Scientific and technical knowledge often entails the most complex of exchanges.

Valuing scientific and technical knowledge in terms of the uses to which it is put relies heavily on an understanding of the social behaviors of users. Indeed, an alternative notion of value almost necessarily requires an alternative view of the behaviors motivating the social organization of science. Our churn model of knowledge value departs significantly from the notion that the market and market transactions are the most appropriate way to understand knowledge development and use. Put most simply, our valuation approach is based on use (not rents or rent-seeking) and our understanding of scientific and technical work is based on the social configurations promoting use (among which market pricing is only one of several influences).

2. The "churn" model: a framework for assessing value of scientific knowledge

Economic assessments of scientific knowledge begin with one fundamental, generally unexamined assumption: the standard for knowledge valuation is price in an open market. To be sure, economists labor mightily to cope with widely recognized problems related to the economic valuing of knowledge, including, most conspicuously, the spill-over and free-rider problems occurring as a result of the joint consumption properties of knowledge. But the analytical difficulties the nature of the "commodity" (scientific knowledge) sets for economic measure and valuation theory are acknowledged by all. An imputed advantage of our churn model is that it provides a framework for analysis of capacity, specifically, the capacity possessed by particular scientists and technologists (their "scientific and technical human capital" (Bozeman et al., 2001), as embedded in the social networks and research collectives producing scientific and technical knowledge (their "research value collectives" (Rogers and Bozeman, 2001; Bozeman and Rogers, 2001).

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[2] James Scott's analysis in 1976 of social transactions in modem peasant villages analyzes "embedded economies", ones in which there is no separation of economic from social life and, indeed, no concept of economy apart from need. Exchange is based on collective interests where the transcendent interest is the need to maintain subsistence. Indeed, Sahlins (1972, p. 76) maintains that "to speak of 'the economy' of a primitive society is an exercise in unreality. Structurally, 'the economy' does not exist". Pre-market peasant village "economies" exist on reciprocity norms in (Booth, 1994). The emergence of a disembedded, semi-autonomous economy, premised on valuation of privately-held goods, replaces reciprocity with norms, beliefs, and (ultimately) laws centering on alternative means of producing and allocating transitively-valued commodities. It seems to us that exchange of knowledge in science has as much to do with the pre-market embedded economy (e.g. reciprocity, recognition of collective interest) as with the disembedded legal economy (e.g. intellectual property rights, value based on price).

Rather than focusing specifically on discrete projects (the usual realm of cost-benefit analysis) or national economic productivity accounting, our alternative focuses on capacity within fluid, dynamic research collectives.

2.1. The churn model's core assumption: "use-transformation-value"

The churn model assumes that use and valuation of knowledge are identical. Information without use is information without value. Once put into use, information becomes knowledge and, perforce, has value. The value is not transitive among users. The appropriate "metric" for value is as diverse as the aspirations of users, including not only pricing and profits, but status, curiosity, aesthetics and mastery of the physical world.

Knowledge (information-transformed-in-use) gives rise to new information encoded in inscriptions (e.g. presentations, papers, procedures, techniques, blueprints, skills, and so on). This new information has no value until (unless) it is, in its turn, put into use. Information may lie fallow and valueless. Or it may be used, either by its initial creators or by other individuals. As the information is used (producing new knowledge), it takes its place in a cycle of unpredictable periodicity, a cycle which may or may not lead to new uses and, thus, further information and perhaps, in another cycle of use, new knowledge. In each instance, as information is used and, thus, by its application transformed into knowledge, discernible value is created.[3]

2.2. Non-transitive value: the "equality of use principle"

A major assumption of the churn model is the *equality of use principle*. This principle, an enabling assumption, stipulates that all uses are expressions of non-transitive value to the user and, thus, the observer must remain neutral about the value of uses. One can observe aspects of the *character* of use (as we explain below) such as repetition, intensity and range of uses. An evaluator can assess the relative merit of social configurations with regard to their ability to produce new uses. But use itself is non-transitive.[4]

The equality of use principle is a direct consequence of the observation that scientific and technical knowledge does not contain its consequences and potential within itself. In other words, the quality of the output of research or even its truth cannot really be a cause of its success because it cannot be assessed before it is used. Rather, quality of research output is a result of its success among the relevant clients (e.g. research affecting researchers; hired students; adopted innovations). Clients' use *defines* success. Therefore, the array of uses that reflect attribution of value of research output must be established empirically rather than being imposed a priori.

Though an important enabling assumption for our model, the equality of use principle may not be intuitively appealing. The skeptic might reason: "this approach puts crackpot designs of perpetual energy machines in the same category as articles published in the *Physical Review*". Actually, it may sometimes put the crackpot design "ahead" of the scientific article. If nobody uses the scientific design and many use the crackpot design, the latter is knowledge and the former is not. In defense of this definition of knowledge let us consider: (1) phrenology was once received wisdom; (2) ideas for airplanes were resolutely crackpot. Presumably, there was at one point a strong market demand for "phrenology services" and, at early junctures, almost no *market* demand for ideas about flight. Thus, market evaluation provides,

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[3] The terms "information" and "knowledge" have been used in a wide variety of ways, serving many purposes. Therefore, we provide our own distinctive (though not altogether novel) definitions. *Information*: Descriptors (e.g. coded observations) and statements (e.g. language-based synthetic propositions) concerning empirically-derived observations about conditions and states of affairs in the physical world and the real of human behavior. *Knowledge*: Information put to use in furtherance of scientific understanding (i.e. empirically-based, generalizable explanation of states of affairs and behavior) or in the creation, construction, or reshaping of technological devices and processes. Scientific or technical information rates to knowledge through interpretation. In itself, information has no meaning, and hence no actual value; it suffices that any actor in an R&D context believes a piece of information has scientific or technical meaning. Meaning is attributed to information when it is *used*. In our approach, use is the criterion by which knowledge is gauged.

[4] The use value of scientific knowledge resembles the use value of art. Thus, a large Calder sculpture may, at the same time, serve as a source of aesthetic appreciation and as a child's jungle gym. Similarly, a single scientific report may serve as a spur to additional research and knowledge, a basis for public policy-making and the knowledge embodied in physical technology.

at best, a lagging indicator of enduring value of knowledge.

While our purposes relate more to explanatory than normative theory, the churn model's tenets of value neutrality (or, at least, intransitivity of value) give rise to a troubling moral question. If the value of knowledge resides in its use does this imply that a rich set of uses for morally corrupt purposes is somehow "good"? Many extreme examples come to mind, such as World War II medical experiments on live patients, use of physics knowledge for nuclear terrorism, or even the origins of linear programming as a means to optimize the efficiency of bombing routes. One could make the case (though the moral reasoning is not straightforward) that in each of these illustrations scientific and technical knowledge was either developed through immoral means or used for immoral means. Our theory of value is *not* a theory of the good. It is possible to consider the scientific and technical knowledge contributing to the development of automobiles without reference to the tremendous array of outcomes that seem to have resulted from the automobile's worldwide adoption and diffusion. The automobile facilitates the movement of people and goods, but it is also complicit in the death of hundreds of thousands of crash victims. The automobile has changed residential patterns, consumer aspirations, air quality and even birth rates. But understanding the value of the automobile does not require making a moral judgment about each of its myriad and causally complex outcomes. Similarly, the intellectual descendants of the operations research knowledge that began with linear programming of bombing patterns is now used for ambulance and traffic light optimization and Internet packet switching algorithms. The examples underscore the need for a neutral assessment of scientific and technical knowledge. One can, at the same time, deplore (or applaud) uses of knowledge and assess knowledge uses disinterestedly as being more or less rich, widespread, powerful, or efficacious.

3. Value implications: the churn model as an index of capacity

One likely objection to a churn model is that it yields no precise index for quantitative evaluation of scientific and technical knowledge. The model is, indeed, open to this charge. However, we feel the model has important implications for qualitative evaluation and for the conceptual framing of quantitative evaluation. A strong point of the churn model is that it encourages analysis of the value of *capacity*, not just output. We feel that one remedy to shortsighted or premature evaluation of scientific and technical knowledge is to consider it in terms of its contribution to capacity, the ability to produce new knowledge and to sustain knowledge churn.

Two key concepts represent dimensions for analysis of the churn model—"scientific and technical human capital" (Bozeman et al., 2001; Dietz et al., 2000) and "knowledge value collectives" (Rogers and Bozeman, 2001). In the churn model, scientific and technical knowledge value occurs in both use *and* user. Participation in the churning process of knowledge-use-new knowledge-new use enhances the individual's capabilities by affording new skills, training, embodied knowledge, tacit knowledge and social capital in the form of network ties. Thus, the churn of science knowledge creates and enhances scientific and technical human capital, the sum of the user's knowledge and social ties pertaining to the use of knowledge. Since science, technology, and its application are inherently social processes, the scientific and technical human capital of the individual contributes capacity to networks of knowledge creators and users (Shrum, 1985). Our term for this network of creators and users is a *knowledge value collective* (Rogers and Bozeman, 2001).

3.1. Scientific and technical human capital and the churn model: capacity as embedded value

Economic pricing answers the question "what is the current monetary exchange value of the knowledge?" We are interested in the "embedded value", value at the hedonic level. In our search for embedded value, we began with a fundamental question: "what motivates human beings to acquire scientific and technical knowledge and what do these motives imply about valuation?" While a deep answer to this question would require much more space than we take here, a surface answer suffices for our purpose. Among other possible reasons, individuals seek scientific knowledge to make an economic profit (i.e. to enhance their material wealth), to satisfy their curiosity, to develop technology (broadly defined), to enhance their skills, insights and mastery of their environment, to create knowledge for its own sake, and for any of a number of social and psychological reasons not specific to science (e.g. self-aggrandizement, fame, social pressure and role conformance).

Most motives for use of science knowledge are equally good answers to the question "why do people search for information, any information". While not completely distinctive, two closely related motives for pursuing scientific and technical knowledge often differ markedly from motives for pursing other types of information. One seeks scientific and technical knowledge to create technology or to create new scientific and technical knowledge. Related, one seeks scientific and technical knowledge to enhance one's personal scientific and technical human capital, thereby improving one's potential for developing technology and creating new scientific and technical knowledge.

The key issue for us is how to develop means of assessing value corresponding with the actual motives for seeking scientific and technical knowledge. Our answer: focus on *capacity*. If one has measured obtained capacity, one has measured something more important than market value. If one can understand the ability of individuals and, particularly, networks of individuals, to contribute further to scientific and technical knowledge, then one knows something of greater value than the price of knowledge.

By "scientific and technical human capital" (S&T human capital) we mean the sum total of personal skills and resources the researcher brings to his or her work (Bozeman et al., 2001). S&T human capital includes not only the individual human capital endowments included traditionally in labor models (e.g. Becker, 1962; Shultz, 1963), but also the individual scientist's tacit knowledge (Polanyi, 1962; Senker, 1993), craft knowledge and know-how (Bidault and Fisher, 1994). S&T human capital further includes the *social capital* (Bourdieu, 1986; Coleman, 1988; Dietz, 2000) that scientists draw upon in framing research and technological questions, creating knowledge, and developing social and economic certifications for knowledge.

Fig. 1 provides a model of S&T human capital. Fig. 1 depicts not only the internal resource dimensions of the scientist (e.g. cognitive abilities), but also external resources directly relevant to the production of knowledge and technology-social capital and embedded network ties. The different shapes of nodes implies the convenience of recognizing qualitatively different types of linkages. Those differences may be based on the institutional setting of the network partner (e.g. industrial, academic) or the role (e.g. entrepreneur, funding agent, scientific colleague). Our point is a simple one: scientists employ a wide variety of network-mediated resources to enable their work and these resources—this scientific, technical

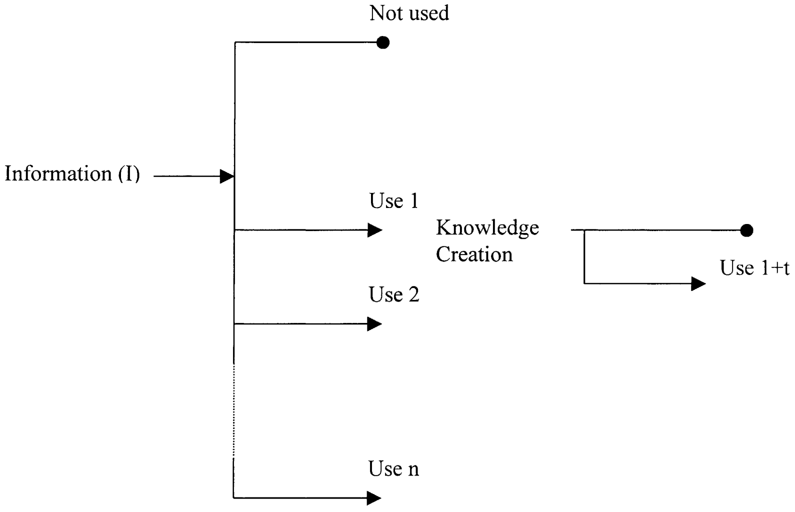

Fig. 1. Use and transformation model of knowledge value creation.

and commercial social capital—is uniquely configured for any particular scientist. While this depiction focuses on the individual scientists, a similar map can be drawn for a research program, a single research study, a laboratory or virtually any social organization or set of social interactions (for elaboration, see Bozeman et al., 2001).

We argue that understanding the *value* of scientific and technical knowledge, including its value the individual scientist, requires a view of the social context of scientific work (for a complementary argument see Audretsch and Stephan, 1999). Much of S&T human capital is embedded in social and professional networks, technological communities (Dasgupta and David, 1994; Liyanage, 1995), or "knowledge value collectives" (Bozeman and Rogers, 2001). These networks integrate and shape scientific work, providing knowledge of scientists' and engineers' work activity, helping with job opportunities and job mobility, and providing indications about possible applications for scientific and technical work products. The value of knowledge and technology produced in formal and informal networks of scientists depends upon the conjoining of equipment, material resources (including funding), organizational and institutional arrangements for work and the unique S&T human capital embodied in individuals. At any level, from the individual scientist to the discipline, field or network, value is capacity—capacity to create new knowledge and technology. Thus, the key value question is "what factors enhance capacity, diminish it or simply change the reservoir of capabilities inherent in individuals and groups?"[5]

The drive to create technology and knowledge and the desire to enhance one's S&T human capital corresponds roughly at best with the desire to accumulate wealth and with the contemporary market value of knowledge. The history of invention shows countless cases where individuals act in a manner poorly explained by economic models. Invention and much of science has very little to do with the world of prices and material wealth. Even in the business world, the sharing of knowledge among competitors is only partly attributable to economic interest. Often it pertains to shared norms of curiosity and the desire to pool skill development.

Fig. 2 depicts the churn model and the individual researcher's place within it. The figure shows the individual's S&T human capital accumulation and shows external linkages, including to the "knowledge value collective" (discussed below in detail), the set of creators and users of a particular science knowledge set. The model assumes, without elaborating, a reservoir of "internal" human capital of the S&T human capital model (presented in Fig. 1. For elaboration see Bozeman et al., 2001). The model hypothesizes that individual scientists begin with "x" dimensions and valences of the major elements of internal capacity and those dimensions and valences change over time, chiefly as a result of interactions within networks and particular scientific projects. Generally, the range of knowledge and network ties is expected to expand over time (doubtless with empirically identifiable threshold effects), enhancing the individual's S&T human capital and value to the network (see Mangematin, 2000 for discussion of recent Ph.D. graduates).

This model relates closely to the churn model inasmuch as the driver for accumulation of S&T human capital is direct participation in the acquisition, use, and transformation of knowledge. In using knowledge, the individual creates new information (available to other users and transforming into knowledge once used) and, at *the same time*, enhances his or her individual S&T human capital. Since scientists inexorably work in social networks (inexorably because their knowledge is validated by other users), the increments of individual S&T human capital are, in turn, increments to the network (or, in our terms, "knowledge value collective").

3.2. Knowledge value collectives: social configurations and the churn model

The term "collective" has been used in many different ways in the social sciences, but less often in social

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[5] Let us emphasize that none of this discounts the more traditional aspects of individual scientists' talents, such as the ability to conduct computer simulations of geological fracture patterns or the ability to draw from knowledge of surface chemistry to predict chemical reactions in new ceramic materials. Our concept simply recognizes that in modem science being scientifically brilliant is only necessary, not sufficient. In most fields, a brilliant scientist who cannot recruit, work with, or communicate with colleagues or who cannot attract resources or manage them once obtained, is not a heroic figure but a tenure casualty or one or another variety of underachiever.

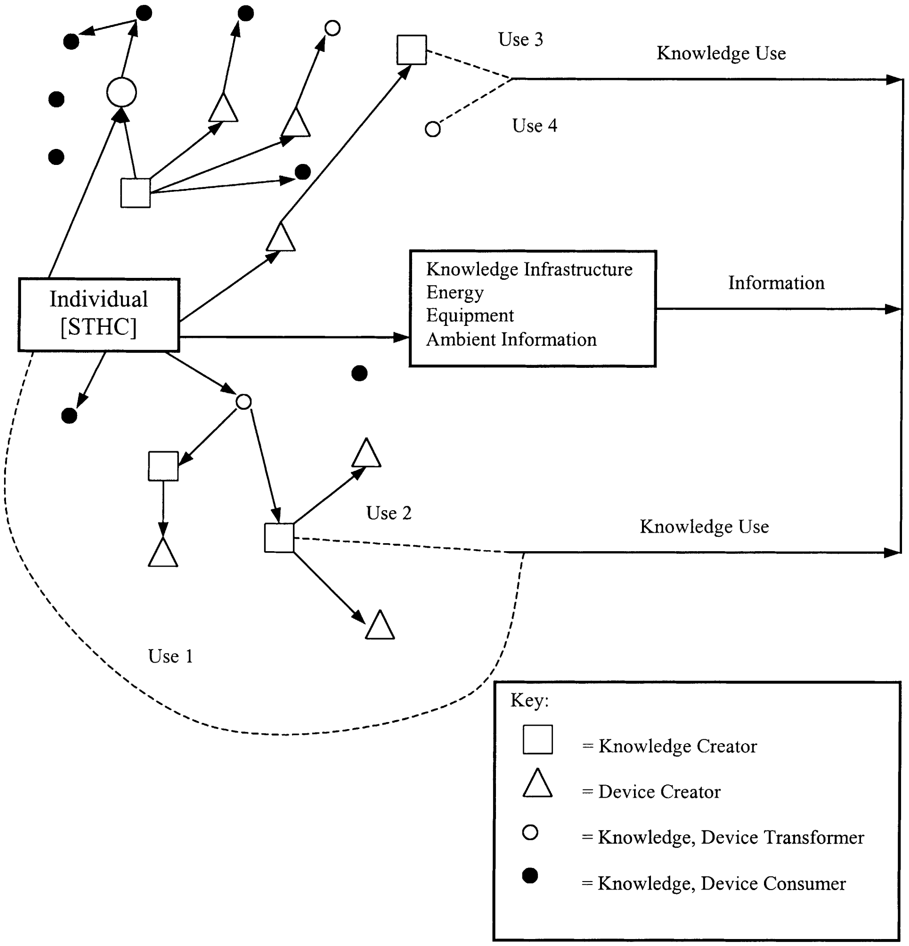

Fig. 2. Churn model of knowledge use and transformation.

studies of science. Our use of "collective" in much the same as the lexical sense, in the first definition of the *Webster's Unabridged Dictionary* (1983, p. 367), as "common possession or enjoyment; as in a *collective* of goods". Our interest is in the common possession and enjoyment of information.

There are several reasons why we prefer to speak of *collectives*. We do not use the term *network*, for instance, chiefly to avoid the many layers of meaning one must peel away from *network*. The term "network" is used in many different ways in, and generally to good effect, in social studies of science (e.g. Callon, 1997; Bidault and Fisher, 1994; Valente, 1995; Laredo, 1998). Since we draw to some degree from each of these quite disparate sources it seems easiest way to avoid confusion among the many meanings of network by just avoiding the term altogether.

We define a *knowledge value collective* (KVC) as a set of individuals connected by their uses of a body of scientific and technical knowledge (for detailed treatment of the knowledge value collective and related concepts see Bozeman et al., 1998; Bozeman and Rogers, 2001; Rogers and Bozeman, 2001). As users of information, the KVC confers value to the information. It is a loosely coupled collective of knowledge producers and users (e.g. scientists, manufacturers, lab technicians, students) pursuing a unifying knowledge goal (e.g. understanding the physical properties of

Table 1
Comparing economic and churn theories of knowledge value

	Churn theory of value	Economic value
Valued object	Capacity to produce new uses: S&T human capital	Discrete products: papers; patents; jobs created
Standard or index of value	Range and repetition of uses	Price in the market of products traceable to scientific knowledge
Transitive value of knowledge	No	Yes
Valuing process	Embedded value	Exchange value
Knowledge value generator	Collective	Individual/project

super-conducting materials), but to diverse ends (e.g. curiosity, application, product development, skills development).

The persons within a KVC reshape information into new packages of knowledge (including technology, which we view as a physical embodiment of knowledge).[6] The size of a KVC varies enormously from (in-theory) a minimum of two (the original creator and a user other than the creator of information) to thousands or more. Typically, the size of the KVC will depend on such factors as general awareness of the body of knowledge, the breadth of its uses, the skills required to obtain and apply information. There is no requirement that members of a KVC interact, know one another or even be aware of one another; the only requirement is joint use of a body of information (and, in their use, creation of knowledge value).

We developed the KVC concept, rather than employing related concepts such as socio-technical network or scientific community, because we felt that our model deals with content not easily conveyed by existing concepts. Most important, we wished to emphasize the linkages among persons who are employing related knowledge to develop separate uses. In some instances these separate uses are pursued by scientists using related knowledge for different research objectives. But some uses are much more disparate, such as simultaneous uses for, respectively, fundamental research, technology development, technical assistance, and building research equipment. There are many instances where the same reservoir of knowledge feeds a great many diverse uses. Two contemporary examples are the diverse uses of knowledge about lasers (Dietz and Bozeman, 2000) and magnetic resonance imaging (Bozeman and Donez, 1996). Often the persons engaged in the disparate uses were not aware of one another's needs, uses, or knowledge contributions but, nonetheless, could be viewed as tied by a set of common knowledge needs. Among our more than thirty case studies of government-funded R&D projects and programs (Bozeman et al., 1998; Rogers and Bozeman, 2001) we found a great many instances in which a common knowledge base contributed to a remarkable array of uses (and, perforce, new knowledge). Our KVC concept was designed to promote research on persons who have shared needs for scientific knowledge, but highly diverse uses and values for it (for a discussion of directly interacting sets of diverse knowledge users see our case studies of "knowledge value alliances" (Rogers and Bozeman, 2001)).

We can contrast the KVC with a "scientific discipline", a concept long important in the social study of science, albeit one strained by recent developments in the nature of scientific work (see Turpin et al., 1996). Table 2 presents a comparison of both notions along a series of dimensions pointing out the main characteristics of each concept for each dimension. We present the information in Table 1 as an archetype, assuming that we have captured modal characteristics of disciplines and knowledge value collectives, but with the understanding that there is substantial variance around those modal tendencies.

Perhaps the chief difference between the KVC and the discipline, as Table 2 shows, is the range and diversity of the inhabitants. During most of the history of social studies of science, the focus

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[6] Knowledge consumers who do not reshape the knowledge but simply consume it without transforming it (e.g. read a newspaper report of a new technology, read a scientific paper, use a commercial software, drive a car) play an important role in innovation and knowledge creation by providing feedback. But "pure consumers" are not considered part of the KVC.

Table 2
Comparing knowledge value collectives and scientific disciplines

	Knowledge value collective	Scientific discipline
Inhabitants	Scientists, technicians, entrepreneurs, inventors, manufacturers, science students	Scientists
Knowledge goals	Heterogeneous and sometimes incompatible	Homogeneous and usually compatible
Norm consensus	Low	High
Barriers to entry	Low	High
Social control	Low	Usually high
Boundaries	(With other KVCs): poorly demarcated, highly permeable	(With other disciplines): somewhat demarcated, somewhat permeable
Communication patterns	Fragmented and dispersed, but concentrated according to knowledge use	Formal: comprehensive and dispersed; informal: segmented and concentrated
Evaluative mechanisms	Highly diverse and use-specific	Often institutionalized (e.g. peer review)

has, understandably, been on scientists, especially academic scientists within disciplinary frameworks (Shapin, 1992). The discipline is an easier target. Compared to the scientific discipline, the KVC is much more heterogeneous with respect to norms and goals, member ties are much weaker and more fluid, and social control mechanisms are, in some instances, virtually nonexistent. Disciplines leave easy to follow communication "tracks", whereas the KVC has more diverse, less patterned and less intense communication. The advantage of a focus on the KVC is that it better reflects the social environment in which knowledge is developed, used, and transformed.

The pursuit of knowledge is constitutive of both the KVC and scientific disciplines to the point that in both cases the content of the knowledge has a bearing on the identity and boundaries of both. Knowledge about magnetism and chemical bonds puts those studying each in different disciplines in a similar way as the applications of nuclear magnetic resonance and the development of super-conducting materials puts those working on them or using them in different KVCs. However, the binding effect of knowledge pursuits works differently in each case. Fundamental knowledge of the phenomena in the field is always the touchstone of a scientific discipline even when, in practice, its members carry out a variety of activities that do not directly contribute to that objective. The center of the field will be occupied by those who are contributing new knowledge of a fundamental sort. This is not the case in a KVC where the "hot" topic can vary greatly in the sort of knowledge that is at issue. At one point it can be the characteristics of a new material, then the new manipulating possibilities offered by a new experimental technique, then the emergence of new applications for a well known phenomenon, and so on. This also makes the profiles of its central actors different at different times, from academic scientists, to program managers, to industrialists and marketers.

As a result, KVCs are much less stable over time as their focus and composition shift. Scientific disciplines, on the other hand, do not tend to disappear once established as long as they can justify their social organization as the correlate of a "piece of the world". As a result, as members of disciplines, scientists tend to be more conscious of the boundaries between them even though much of their work may challenge them. KVCs, on the other hand, tend to overlap most of the time because of the multiplicity of uses that are relevant to their members. Thus, the KVC's density of uses around the main scientific and technical knowledge focus is what makes them visible rather than the limits at the periphery.

The KVC conceptualization represented in Table 2 is, of course, an archetype. In a later section of this paper, we apply the churn model and its knowledge value collectivity concept to two cases, one an important case in the history of science and technology—the development of the Internet, and the other an unusual interaction of managerial and knowledge goals in the formation of a plant biology research network. The objective is to determine if the churn model and the KVC conceptualization holds up against the complexity of this instances of the use and transformation of scientific knowledge.

3.3. The knowledge value collective and the churn model

Put simply, the churn model is the process (information-use-knowledge transformation-system transformation) enacted within the KVC. Similarly, individual actors ply their S&T human capital in the churn process and as contributing (and exploiting) members of the KVC. The KVC validates the knowledge produced by individual members (though not through conventional social controls) and relies on the constituent members' S&T human capital for its functioning and growth (Fig. 2). Provides a model integrating the KVC and S&T human capital flows within the churn model.

As Fig. 2 indicates, one creative entry point (multiple entry points are possible) begins with the individual scientist plying her internal capacity, augmented by social capital gained from association with the KVC, on a knowledge application (use) set by the prevailing state of knowledge and resources within the KVC as well as her own imagination and skill. In working with extant knowledge, the individual creates new information by developing a new use (extension, technological application, etc.) for extant knowledge. The new information is presented in some manner (research article submission, technological device, new research process) to the user collective, the KVC. The KVC may, essentially, ignore or invalidate the new information bringing the churn process to a (perhaps temporary) dead end. Or the KVC can validate the new information and, when used, transform the information into knowledge value, thereby perpetuating churn. In the latter case, use by the KVC, the KVC itself is transformed as a result of an advance in its available knowledge (technology, know-how). Likewise, the process is transformative for the individual who, by her knowledge creation efforts, necessarily increments not only the KVC's reservoir of S&T human capital, but her own as well.

In Section 4, we try to illustrate the workings of the churn model within a KVC by now quite familiar—the collective of researchers, technology developers and promoters who gave rise to the set of knowledge uses we now refer to as the Internet.

4. The churn model and the development of the Internet: an illustrative case

We feel that the history of the development of the Internet provides an instructive illustration of the churn model and the workings of a KVC. While we draw a bit from our previous work on the Internet (e.g. Bozeman, 1997; Roessner, 1997; Rogers, 1998), our chief purpose is illustrative rather than to extend knowledge about the Internet's increasingly controversial history (e.g. Rogers and Kingsley, 1999).

The development of the Internet was a direct result of the dynamics of science that we are proposing to model with the notion of KVC. It cannot be explained simply by isolating a technological device or method and interpreting everything that followed as the inevitable unfolding of its potential. This has been attempted though, and a conventional assessment of the Internet as a device that has been "invented" is based on the development and features of the TCP/IP protocols (Abbate, 1999). On the one hand, the applications are what users are most interested in and not the protocols themselves, though the genius of the protocols lies in the applications they are capable of supporting. This is a very clear case in which the value of the protocols "remains to be seen" until applications are developed and the protocol's use is valued through the applications. The Internet as a system has many components that represent semi-autonomous domains of knowledge in which we observe the dynamics of churn model's use and transformation of scientific knowledge.

The Internet's multiple domains of knowledge feature has been there from the beginning, in part because of the convergence of knowledge uses feeding the Internet. Our interviews with Len Kleinrock, the UCLA professor who was in charge of the early host-to-host protocol projects for Bolt, Beranek and Newman, Inc. (BBN), described the knowledge use ferment of the 1970s:

> Networking didn't really catch fire until about 1967. Then in 1975, BBN became a center for testing and was working on satellite packets and ground radio. This led in one stream to cellular and wireless. Now we had Arpanet, satellite and packet ratio. With these very different networks this led to a need for an Internet so they could interact.

> Vint Cerf put together two protocols for this. The wireless stuff also led to Ethernet, applied by Bob Metcalf (Bozeman, 1996a).

This set of parallel developments is, of course, no more remarkable in its patterns of divergent use of knowledge than is Paul Baran's original network algorithms. As is by now well known, Baran's packet switching research was developed in connection with plans for sustained transportation routing during a the event of a nuclear attack. His earliest work was, in turn, affected by work from another field:

> I got very interested in neural networks and what we know about the brain and I had many conversations with McCullough at MIT and with people at the Brain Institute at UCLA. At the time we didn't know a lot about the brain. But even then we knew it was the closest parallel to what we were interested in-criss-crossing connections (Bozeman, 1996b).

Two of today's main applications of Internet technology further illustrate the churn model's dynamics within a KVC. Electronic mail is one of the most familiar and popular Internet applications. The original application for exchange of messages was developed almost as an aside without anticipating that it would be responsible for driving the growth of the network for a significant period. From this experience, the entire development pattern of the Internet has been termed "user-driven" and in this strict sense it is quite true. The caveat, of course, is that these initial users of what became the Internet did not much resemble typical users of broad communications systems such as the telephone. These early users were almost exclusively members of the same scientific community that was developing the network and, as such, their uses of the system had considerable input in shaping its path. Indeed, their uses led to the "discovery" of electronic mail and its development into a full blown application with new features adapted to the needs of a more diverse public (Rogers, 2000). The development of e-mail illustrates knowledge processes of the churn model: one set of scientific information uses transforming into the knowledge required for a subsequent set of largely unanticipated uses.

A second case of this nature was the development of the World Wide Web that is the main window to the Internet for almost all users. This is true to the point that oftentimes World Wide Web and Internet are used as synonyms. This application was originally developed in scientific circles for facilitating scientific collaborations from remote locations. Each team member or location would have a site where their contributions were posted, along with links to files and other information resources. The early prototypes for what became the Web were actually tested as early as the late 1970s, as reported by David Mills (described by Vinton Cerf as "the grease monkey of the Internet" (Bozeman, 1996c)):

> Jan Postel designed early protocols, they all have his stamp, either as a manager or engineer. He thought up the "Internet bake-off" where several of us would get together and design protocol sessions, putting together people with different protocols to see if they could talk to one another. We would also try to break each others' software (you would get "points" if you could break someone's software, so we would all design Kamikaze packets to break software). This all happened in rooms in West LA in the late 1970's to 1982 (Bozeman, 1996d).

The extension of these early protocols exploded as an infinite number of variations were developed for myriad applications outside of the world of science. Yet another example of the churn model's use and transformation in which it would be very hard to believe the claim that the first developers had today's reality in mind when they started. The value of the World Wide Web grows several orders of magnitude daily with the uses and knowledge transformations by millions of people around the world. In the case of knowledge churn for more conventional scientific problems, a similar dynamic occurs, except that the number of participants is obviously much smaller and the number of uses and transformations developed less rapidly than we find in the Internet case.

In sum, the actual path of the Internet's development, from the technical ability to network computers into a broad, economy-wide infrastructure, reflects the heterogeneity and multiplicity uses of knowledge within an especially broad KVC. The Internet came about through the normal (if normally "messy") knowledge churning processes of the academic science and technology community. The Internet did not develop as an application of knowledge created to fulfill the central goals of scientific disciplines (for related findings in other scientific fields see Chompalov and Shrum, 1999). Rather, it was an outcome that resulted *indirectly* and somewhat haphazardly from the simultaneous pursuit of diverse goals within a diverse knowledge user/producer community (Rogers, 1998).

It is clear that the value of the Internet could not be assessed properly solely by estimating the market prices of its components. What is the market value of queuing theory? Or is the price of e-mail software and transactions a good indicator of the value of electronic mail? Absent knowledge of the singular dynamics of the Internet's knowledge churn processes it is difficult to understand the Internet's development or its value. he creation of value associated with the Internet would be grossly misunderstood. For example, if the development priorities had been set by feeding back the market signals available at the time, the effort of developing either electronic mail applications or the World Wide Web would not have been undertaken. These innovations were both pursued in an effort to create capacity for scientific work and were charged off as research subsidies. Further, in the process of developing these two key Internet applications, thousands of people enhanced their S&T human capital as they learned about the nature of these computer applications, the interactions of applications with the behaviors and expectations of groups of users, about the portability to available computer platforms, and the challenges to computer infrastructure management.

4.1. Composition and activities of the Internet KVC

An unusually complex KVC formed around the Internet during the period in which the academic science and technology community began catalyzing the conversion of a specialized computer communications technique into a broad information infrastructure. The set of people connected by their uses of knowledge about the Internet included several subsets. Each of these had its own distinctive goals. The Internet, however, tied them together into the larger set that we have identified as the Internet KVC. We will mention here the four main subsets or components of the KVC that played the most significant role in bringing the Internet out of its esoteric context of research labs to society at large. Each of these diverse sets knowledge users and producers made crucial contributions to what became the Internet, not through a rationalized, sequential innovation process, but though a chaotic, but obviously fruitful, churning of disparate bits and pieces of scientific and technical knowledge.

4.1.1. The scientific community of computer science

The implementation of the ARPANET was driven by the research community that had contracts from ARPA in order to share computer resources. It later became a key means of communication and information sharing that gave prominence to the groups that were on the network over the broader computer science community. The rest of the computer science discipline felt this difference very acutely and argued that broad access to computer networking was critical for the survival of the discipline as a whole. There were several practical and bureaucratic reasons why the ARPANET was not directly extended, but with involvement of the National Science Foundation, a logical network, CSNET, with a combination of networking technologies was implemented. This network became a significant means for the discipline of computer science to acquire full status as a legitimate field of basic science. It extended internationally providing the initial critical mass for an international Internet and it proved the viability of networking as some of the questions about management and support of such networks were put to the test for the first time.

This subset of the Internet KVC was composed of most of the members of the computer science academic discipline. It included those researchers and graduate students who were on ARPA contracts and had access to the ARPANET. It also included the faculty and students of computer science academic departments of the top 50 or so US universities that did not enjoy ARPANET access and realized the need to extend such networking capabilities to the rest of the discipline for these academic departments to remain viable. The interesting point to be made here is that the normal functioning of the discipline solving the problems it recognizes for itself was not what made this group into a KVC even though it is essentially composed of people within a discipline. Larry Landweber was the chair of the Computer Science department at the time and one of the leaders of the implementation of CSNET. He recalls:

> We got together and we wrote an initial proposal for this thing we called CSNET and it got submitted by the University of Wisconsin and I think we submitted it in the fall of 79. Well, it was reviewed with really devastating results. I mean, the reviews were uniformly bad. They ranged from “these guys are theoreticians and, you know, chairmen and they don’t have a clue how to build a network or what networking is about”. And they were right. At the point we submitted the proposal I don’t think any of the people who were Pi’s on it had ever worked on a network (Rogers, 1995b).

An interesting illustration of the churn model’s use and transformation principle is the fact that the financial and bureaucratic constraints of the constituency of the CSNET led to the implementation of the interconnection of the ARPANET and public data networks using the X.25 protocols. This part of the development of CSNET was led by David Comer at Purdue beginning in 1981. They used information about the operation of both types of networks, which were conceived for very different purposes and devised a way to present users with the functionality of the ARPANET while accessing the network via an X.25 connection. The result was not only that this technical goal was achieved but that, in turn, a new understanding of the possible solutions to new networking problems emerged and led to the proposals for Internet working standards at the international level (Abbate, 1999, p. 45). In this example, there are two steps in the use and transformation process. First, the state of the art in ARPANET technology and X.25 is input as information for the task Comer and colleagues encountered. They transformed that information into knowledge both about the problem at hand and the background technologies. Then the use of information about this experience was transformed into knowledge of standard setting in international Internet working.

In a sense, the computer science community’s role in developing the Internet is a useful illustration of discipline based churn processes. The diversity of uses may be somewhat less diverse, but the role of social and political factors exogenous to the field is as clear here as in cases of broader KVCs.

4.1.2. Computational chemists and physicists

More or less at the same time, the late 1970s to early 1980s, physicists and chemists that oriented their research to the use of supercomputer simulations reported a crisis in their midst due to the lack of access to supercomputers in the United States. The difficulties arose because the mainstream of the disciplines of chemistry and physics did not deem simulations a fully legitimate way of attacking basic science problems. As a result, American universities did not see the need for installing such machines on campus and for more than a decade after they had shown their potential in circles associated with the Department of Energy; no university in the country acquired one. By the early 1980s, a few of the younger generation of these scientists had risen to international prominence, including Nobel prize winner Kenneth Wilson. This new generation used their enhanced reputation to convince the scientific establishment and the government support structure of science to address their needs. As a result, a new program was put in place in the National Science Foundation to establish several supercomputer centers that would be made available to the entire academic community of science via a national network. Once again, the direct expansion of ARPANET collided with bureaucratic obstacles and NSF took on the networking task as well.

One significant example of the churn model’s use and transformation process has to do with the use of various computer network protocols with supercomputers. This application of networks had not been attempted and the need for remote access to supercomputers by academic computational scientists generated a variety of uses of computer networking information. Initially there was some disagreement on this because of the different needs that had to be satisfied simultaneously. One of the directors of supercomputer centers referred to the protocol choice and implementation TCP/IP for NSFNET as follows:

> . . . at the time they didn’t work. It only worked in the ARPANET in a limited sense. And there was no software available for supercomputers, and so everything they were proposing was an experiment and I had a production facility and so I wasn’t about to make a commitment for my production facility based on somebody else’s theory of how things might turn out (Rogers, 1995a).

The computer protocol information had to be transformed into new knowledge as the protocols were implemented for direct logon to supercomputers via the network. This work was done at NSF sponsored supercomputer centers at San Diego and Urbana-Champaign between 1986 and 1988. This technical goal had important social or political implications in that it demonstrated the possibility of having supercomputers on a general purpose network. The needs of the specialists could be satisfied while aiming at a broader constituency for computer networking at the same time. This proved to be very significant for the actual growth if this system into the Internet global infrastructure.

4.1.3. Program managers and government agency officials

The magnitude of the supercomputer initiative and its network required new funding and the leaders of this group of scientists lobbied Congress and enrolled other science supporting agencies in order to achieve their goals. Two main arguments were put forth to gain political support for the program. First, they emphasized the criticality of the supercomputers to the advancement of American science, which is the classical argument within the postwar "social contract for science" (Guston and Keniston, 1994). Second, they pointed out that the network would also solve the problem of coordinating science by interconnecting research leaders and program managers all over the country. At the same time, they would do so by implementing a general purpose network rather than one that only served their special needs. This tied in nicely with interests of several members of Congress, such as Al Gore, who was looking for a vision of the infrastructure of the future in the wake of the changes in the telecommunications order.

The program managers and other public servants in the government agencies that form the science support system were intimately involved in this process, first, through their membership on panels and advisory boards and, second, by leading networking efforts in their own context that were tied in to the science led initiative. An executive branch committee in the context of the Office of Science and Technology Policy, Federal Coordinating Committee on Science, Engineering and Technology (FCCSET) played a significant role in bringing together interested parties in the academic community and government to keep up the momentum of this initiative. The overall result was that the National Science Foundation led the national networking effort as a program for serving the needs of the natural sciences. Through the effective leadership of the first appointed managers, Dennis Jennings and Steve Wolff, the additional goal of serving broader commercial needs was added to the more traditional goal of serving the infrastructure needs of the science community. Wolff's and Jenning's mediation overcame the obstacles that the expansion of ARPANET had encountered by making their contribution a technological one, at the level of protocol design and implementation rather than expansion through institutional policies. As this effort gained support they were able to open the initiative to the participation of interested private businesses that were able to provide key components, such as Cisco's routers, and network management expertise (MCI/IBM, Merit).

A noteworthy instance of the churn model's use and transformation that related the two subsets of the Internet KVC, computational scientists and government program managers, occurred with the adoption of the model of the network the former were proposing. The knowledge relevant to the adoption decision was at a high level of abstraction and did not involve familiarity with technical minutiae.[7] During the discussions of the implementation of NSFNET in 1984 there were strong advocates for a dedicated system focusing exclusively on the esoteric needs of scientists. Others, especially the government program managers, thought of it as a general purpose system that would eventually grow beyond the needs of scientific research. The latter was presented as a new infrastructure for information alongside the ones inherited from the industrial revolution, i.e. highways, water distributions systems and the like. We must underscore the fact that this model is not purely metaphorical because it did serve to guide specific technical decisions about nodes, protocols, lines, service, and other general features of the system. As one of the leaders of this process said:

> This is what I call an "elite driven democratic result", because although it was driven by an elite, in the end, by far the most important part of the network is its ubiquitous democratic access. But most people, whey they see a wonderful result like

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[7] We do not offer these definitions as "advances" or as possible substitutes for existing definitions, but only as the definitions that best advance our specific objectives of developing a theory of scientific and technical knowledge relevant for evaluation.

> the Internet, with the World Wide Web and Mosaic for instance, say "Oh, that must be why they built it". Not at all. That's totally fallacious"...
>
> There were many people saying it should be built as a democratic thing but they were blocked by the phone companies. And think about the National Science Foundation, the National Science Foundation is supposed to fund e-mail? (Rogers, 1995c).

This approach was adopted in turn by political figures interested in gathering support for this system as the beginning of a new infrastructure. Prominent among them, Al Gore, who began to use this terminology in 1986 after a documented exchange with the scientists at a congressional hearing (US Congress, 1986). Both technical and political consequences followed in the next few years. The approach was implemented in actual networking projects by NSF, other government agencies and private businesses. These projects were structured as contracts for the government and academic sectors. One especially important contract was for Cisco Systems to develop routers. Such government programs as the National Research and Education Network (NREN) and the High Performance Computing and Communications program (HPCC) continued to encourage network and high performance computing development.

The overall result was a decentralized, but loosely integrated process that illustrates our notion of a knowledge value collective: diverse users and producers, many unknown to one another, pursing multiple goals, but nonetheless, influencing one another's knowledge uses by enhancing the available reservoir of scientific and technical information. As is generally the case with a large, complex KVC, the Internet's researchers, technology developers and other actors (including commercial users and government program managers) produced outcomes that different sets of users valued in different ways. The knowledge churn produced outcomes that were more than "the sum of its parts" and that no single user group, even a large well-organized one, could have anticipated.

4.2. Churning S&T human capital in the Internet KVC

Given the size of the Internet KVC, it is impossible to give a full account of the movement of people and the instances of use-and-transformation of information and knowledge that it produced. It is possible, however, to offer a few of the most significant cases of the creation of scientific and technical human capital that was created and how it enabled the development of the business sector of Internet activities.

One of the most prominent examples is Vinton Cerf, who was a graduate student at UCLA when the first ARPANET development efforts started. After graduation, he worked with Robert Kahn, who had been with Bolt, Beranek and Newman (BBN) working on an ARPA contract to develop key components of the early ARPANET. Cerf and Kahn designed the second generation of protocols for the ARPANET, TCP/IP, that became the main Internet protocols a few years later. As soon as ARPANET was ready to make TCP/IP operational on its network, Cerf began working for MCI in 1982 to develop commercial applications of electronic mail services and later became VP for computer networking at MCI. Cerf is probably one of the most influential individuals in bridging the Internet developments from the public and academic sectors to the private sector.

Another example of such S&T human capital impacts is illustrated by the role of Steve Wolff. He worked on computer networks for the Army at the Ballistic Research Lab and played a significant role in the implementation of TCP/IP on the ARPANET in 1982. This experience prepared him to be a key actor in NSFNET and, in 1986, to become NSF's director of networking. He led the actual implementation of NSFNET and its transition from an experiment to a growing service infrastructure. He then joined Cisco Systems, the dominant Internet router company as one of its vice-presidents. His route from NSF to Cisco Systems was not a straight line, nor was the route from the scientists' Internet to the commercial Internet.

> ARPANET was strangling to death from congestion at the time the NSFNET project started. The first NSFNET was simply 40 new nodes on ARPA, selected by NSF. There was not at the beginning any plan for NSF to move into the breach. The idea was to build a network for the NSF community, augmenting ARPANET, but just as a stopgap, ... There were times when it appeared that the NSF plan would not win the day. Some wanted a limited network serving a defined constituency such as

> federal labs or grants recipients. Ultimately, NSF got into NSFNFT not as computing research but as computational physics (Bozeman, 1996e).

The decision to spin-off NSFNET and "go commercial" was even more dicey than NSF's decisions to take the communication infrastructure. Nor did the decision, one fateful for the Internet KVC and its expansion, relate much to any standard model of technology or knowledge diffusion. According to Wolff:

> The research community could not have sustained its research communications needs with government funding. This was one reason why the network had to get out of the hands of government. The network had to be a commodity, not drawing down or research money. Look at what happened (with the cost of) particle accelerators and the supercollider, now just a hole in the ground. It was clear that the appetite for networking was going to be like that. Networking had to be a part of cost of doing business in academic institutions and the only way for that to happen was to privatize it. The idea is not to fund "science" (in one costly central infrastructure) but to fund science as a collection of worthy projects. The notion was not at all popular. We sent out a draft solicitation for public comment and got back 238 pages of response. Many thought it was a terrible idea. Lobbyists from the universities raised hell (Bozeman, 1996e).

The development of the Internet KVC is in many respects instructive. It suggests, among other things, the enormous importance of the learning experience provided by diverse knowledge users in the academic and public sector, solving technical and, broadly speaking, political problems. The Internet KVC also shows the churn of knowledge users and producers. Many graduate students in the research teams that participated in developing bits and pieces of the Internet went on to create their own businesses help lead others. For example, Steve Crocker, who was a graduate student in UCLA in the second generation of ARPANET developers in the mid-1970s, continued in academic positions until the 1990s when he became VP of the Internet security firm, Trusted Information Systems Inc. Others, such as David Mills, have gone from private sector positions to university faculty. The flow of their scientific and technical human capital underpins the Internet KVC and sustains (and is sustained by) its knowledge churn. The case of the Internet's development shows why the KVC includes not only scientific users/producers, but also program managers, entrepreneurs, and others who put their stamp on the many uses of scientific and technical knowledge and influence the value and outcomes of scientific work.

4.3. Summary: "churning" the information infrastructure

The multiplicity of uses of scientific knowledge is a significant feature in the development of the Internet. In telling the story of the Internet's development, many observers emphasize the scientific and technical knowledge leading to the development of computer networking protocols and their application. But it is important to understand that the Internet's development was not simply a case of applying technical knowledge to the solution of a technical problem. The Internet's development cannot fully be understood without recognizing the importance of alternative goals of diverse and sometimes even competing sets of users within the broad KVC. Persons outside the traditional scientific communities and disciplines played critical roles. These "outsiders" (whom we think of as "insiders" within the KVC) government program managers, legislators, agency officials, university administrators, suppliers, and other constituencies critical for the viability of the Internet as a broad infrastructure. The knowledge shaping the Internet included not only queuing theory, digital coding, computer architectures, but also knowledge of the interactive behaviors of different user communities, network management techniques, and various institutional and financial arrangements for network support. The development process and close interaction of people in all these groups reveals the relevance and interconnection of these types of knowledge and its use to each other rather than its differentiation along disciplinary lines. The two top features of our KVC characterization are, therefore, clearly illustrated.

Table 3 provides a summary of the characteristics of the Internet KVC in comparison to the archetype expectations for a KVC and in comparison to the workings of a scientific discipline.

Table 3 shows that the knowledge transformation cycles of Internet research and application match well

Table 3
Comparing Internet KVC with scientific disciplines

	Internet collective	Scientific discipline
Inhabitants	Computer scientists, computational scientists, program managers, agency officials, legislators, university administrators	Scientists
Knowledge goals	Ranging from technical through managerial to behavioral	Homogeneous and usually compatible
Norm consensus	Repeatedly re-negotiated	High
Barriers to entry	Deliberately low	High
Social control	Low and only significant if it threatened the viability of the system	Usually high
Boundaries	Blurred	(With other disciplines): somewhat demarcated, somewhat permeable
Communication patterns	Multiple communication patters as a feature of the system	Formal: comprehensive and highly dispersed; informal: segmented and concentrated
Evaluative mechanisms	Highly diverse and use and constituency-specific	Often institutionalized (e.g. peer review)

against the archetypal characteristics of a KVC, this despite the fact that the Internet KVC has undergone extremely rapid growth and its degree of churn is perhaps unparalleled. At every stage of the development of Internet knowledge, the KVC conceptualization seems to add value to traditional notions of discipline or field. While any of several notions of "network" have some potential to map much the same theoretical space, the churn model and KVC's theory of value-use-and-transformation seems particularly adept for understanding the Internet.

Do the results reported in the Internet case fit the archetype provided in Table 2? In almost every instance, it is important to note, however, that as the Internet has matured there is at least some movement away from the elements of the churn model's archetype KVC. There is a bit more social control with the emergence of various coordinating mechanisms and the communications patterns have become a bit more routinized with the development of research and governance institutions for the Internet. But the essential features remain and still conform closely to the churn models archetype KVC.

5. Comparison case: network for research on plant sensory systems

The generality of the processes of use-and-transformation of knowledge can be appreciated by comparing the Internet case with another from a completely different realm. Research on plant sensory systems is, by and large, a clear case of basic research in plant biology. If the typical assumptions about discipline-based science obtain anywhere, this should be a prominent example. If anything, it is a case that shows how pervasive the dynamics highlighted by the churn model have become even where they would not be expected.

5.1. *Brief history of the network*

Program managers from NASA and NSF working on issues related to the impact of budget restrictions on research funding decided to fund multi-institutional projects in the field of plant biology. This field has found support from NASA because of the agency's interest in the effects of gravity, or its absence, on plant growth. In the midst of a proposal evaluation cycle, the program managers from both agencies decided to select 10 independent proposals that, in their judgment, because of the content of the projects and the capabilities of the labs they came from, seemed to offer most promise for synergistic effects if pursued together.

The program managers made sure the PIs of the 10 projects were willing to participate in the collaboration and made the 10 awards together with a 5 million dollar grant over 5 years to finance the coordination effort. The researchers had never worked together and most, even though they were aware of each other, had not even met. Michael Evans, the PI at Ohio State University who became the coordinator of the network, said

> The panel selected about 10 proposals, I would have been very interested to see how they worked in that panel because it is different from any other multi-institutional approach in the sense that nobody submitted proposals that were in any way related to or coordinated with anybody else. In other words, when you see a multi-institutional or a multi-investigator proposal, people get together and say, "We should do this, here is how we will interact". Then they write the proposal. These are 10 individual proposals, this is what I want to do in my lab. It may be unique. Because of that, I think the review panel must have been quite unusual (Bozeman, 2000).

Almost a year into the grant, the group decided they should reformulate the knowledge goals of their efforts in order for the collaboration to be fruitful. In other words, given the financial and organizational constraints that came with the origin of the collaborative effort, the cognitive content of the research program of the collective had to be adjusted in order make progress toward the expected outcomes. Instead often projects on various aspects of plant responses to various environmental stimuli, they decided to formulate a single project framework within which the efforts of the each lab would work. They decided to focus on the distal elongation zone (DEZ) of the root of Arabidopsis. Different experimental techniques and types of stimuli were employed according to the expertise and equipment available in each lab. But the single focus allowed for the creation of a true intellectual collaboration atmosphere. In the coordinator's words

> We were a year into the five-year funding before we formed a separate project and were never told to form a separate project. We were told, here is the funding for your ten projects, go ahead and interact. We all came to the realization that if we were to interact in the most effective way, we could not have really ten separate projects. That is one thing the funding agencies said they did not want. As soon as we formed the central project, all sorts of collaborations started opening up because we had a focus and we had ten laboratories with quite sophisticated expertise (Bozeman, 2000).

The top down mandated collaboration and the adjustment of knowledge goals is a very significant datum. Ordinarily, scientists are very skeptical of this sort of intervention in their work and tend to resist it if they perceive it as micro-management. However, this sort of relationship with "outsiders" is much more the norm rather than the exception. The actual direction of research clearly responded to conditions that did not belong specifically to the field of research, but to judgments of specialized users, in this case the program managers that expected enhanced results from bringing disparate efforts into contact with each other. The churn model is designed to capture and explain the effects of such "anomalies" in the direction of research. The mutual adaptation of organizational features and knowledge goal is a key characteristic of these systems as we detail in a companion paper (Rogers and Bozeman, 2001).

5.2. S&T human capital and capacity outcomes

The collaboration produced several important scientific results that were published in prominent journals. However, participants considered other outcomes to have much more value than the publications themselves. One of these was a standardized set of experimental procedures. Much previous research into plant sensory systems was not easy to compare and tended not to contribute to a truly cumulative body of knowledge because experimental conditions were very different between labs. The network was forced to establish standards in order to collaborate and make the experimental arrangements relevant to each other's work. This allowed for truly complementary projects that, e.g. combined results in the dynamics of root response to gravity with the molecular genetics of the cells in question. Given that Arabidopsis is a biological model for much research in plant biology, the work of the network with standardized experimental procedures, has led to the possibility of creating a database of phenotypes that mutants develop. This would be an analog of the Gene Bank used in molecular biology. In other words, the impact of this work seems much greater in the capacity it provides not only its own members, but also the entire interdisciplinary collective related to the biology of plants.

The careers of postdocs and graduate students were accelerated by the opportunities offered by the network. This is a direct result from the social capital created in this arrangement. The younger researchers were able to work directly with several prominent researchers giving them experience and exposure that would have taken many more years to acquire had they worked in independent teams. The more frequent participation in fruitful exchanges of ideas with leading members of their field and opportunities to get direct feedback from them for their work allowed them to achieve higher standards of quality much faster. As Evans said:

> Speaking of career trajectories, the students have had the chance to meet some of the preeminent people in the field and they are now on first name basis with those people. They have managed to publish papers with guys who they considered gods and here they are co-authors with these gods (Bozeman, 2000).

This case is very different from the development of the Internet, but shows many of the same features that are highlighted by the churn model. The multiplicity of knowledge goals and uses is a more common feature of any R&D activity than a disciplinary approach would allow. Knowledge is essentially "centrifugal" in its nature. The porosity of boundaries between knowledge activities and "external" factors is crucial to understand how priorities are set and value accrues. This case would be expected to have clear disciplinary features, but is better accounted for with a churn model.

5.3. Is the churn model generalizable beyond these cases?

Is the development of the Internet unique? Of course. In an important sense all instances of knowledge use-and-transformation are unique, but the Internet's development is difficult to even categorize with other cases of technology development. Does this imply that the churn model fits only the Internet's development? We think not. In the first place, the churn model was developed as means of understanding more than 30 distinctive research and technology development cases (Bozeman et al., 1998). In the second place, to be useful and archetype need not completely capture every aspect of every case. The churn model can be applied to any case of scientific and technical knowledge use/production, but in some instances the key features of the churn model will not be as prominent as in other cases. The churn model should prove particularly useful in cases with the following characteristics:

- the KVC's membership is characterized by diversity of knowledge objectives;
- parties external to the scientific community play a particularly important role;
- knowledge development is a corporate, inter-organizational, inter-institutional enterprise;
- work is not easily contained within the confines of a single field or discipline.

In our view, these are key attributes of modern science and technology. To be sure, there are important cases of "small science" breakthroughs by single investigators. But even in these instances one usually finds many of the four attributes listed above.

6. Conclusions

6.1. The churn model as explanation

The development of the Internet KVC cannot easily be understood in terms of the economic value of the knowledge pursued. Indeed, a traditional market-based account would be misleading. In the first place, we witness many instances of government officials proffering the market, sometimes unsuccessfully, ultimately successfully. Decades ago, ATT decided to forego the opportunity to development an early version of the Internet. As Len Kleinrock noted:

> In 1978, ATT was supposed to come out with Bell data network, but it never happened. They made a similar announcement in 1979, it never happened. In 1983, they finally came out with NFT1000 which was a major package switching network which closed down in 1986 with a billion dollar loss. ATT came in late with the wrong products. (Bozeman, 1996a).

While it now seems hard to believe, even as late as 1996, the commercial success of the Internet was by no means a foregone conclusion. As Steve Wolff noted (Bozeman, 1996e), "even right now there is some doubt. Right now the retail prices for access are dropping to the basement with the result that there is no capital formation to build network facilities. There is lots of stains. when we (NSF) went into this, privatization, the private sector had unrealistic prices and no real business plan".

Shortly after that period, revenues for advertising began to increase and public stock trading provided needed capitalization for a wide array of investments. Current accounts, ironically, feature the development of Internet as an enormous success for the unfettered free market (Rogers and Kingsley, 1999). Despite prodigious market contributions to the development of the Internet, it is only recently that the Internet can be validly interpreted by any conventional notion of market theory. For decades, knowledge use and transformation provided insight into the value of the research and technology that has become the Internet. That initial value was chiefly the result of flows of scientific and technical human capital into diverse and ultimately compatible directions. The motives for the flow of S&T human capital varied, but included the need to provide scientific infrastructure, to respond to political demands, to build individual skills, to solve technical problems and, if our interviews are not entirely off the mark, to "play" within elite groups of socially gregarious individuals.

If the history of the Internet provides interesting insights into the interplay of government and business and their respective roles in affecting knowledge use and its value, it is perhaps most instructive with respect to the social configurations of knowledge creation and use. The development of the knowledge brought together in the Internet shows us how little traditional disciplines and institutions help in explaining today's epoch-changing knowledge and technology innovations. While there are certainly bands of discipline-based researchers playing important roles (e.g. the UCLA group of the 1970s), even these groups tend to be highly multi- and inter-disciplinary and they tend to include individuals with highly diverse career trajectories.

The churn model of scientific value, with its attendant focus on the knowledge value collective, provides a fundamentally different basis for understanding knowledge creation, one requiring a great deal of attention to the social forces affecting knowledge creation and downplaying economic incentives and, perforce, market-based valuation of knowledge. However, the model recognizes market factors as one of many potentially significant factors mixed into and affecting "the churn". In many instances, markets and prices will affect individuals motivations and KVC ties, as well as individuals patterns of mobility within a KVC and entering and exiting a KVC. But in other instances these behaviors will have little or nothing to do with markets and prices and much more to do with such factors as need for recognition, curiosity, response to hierarchy, and institutional constraints.

6.2. The churn model and evaluation

If one follows our reasoning and concurs that a churn model of knowledge value provides a view empirically more realistic (or at least more complete) than market valuation, one is nonetheless, left with this question: "even if the churn model provide a reasonable theory of value, what does one make of it as an *index* of value?" We have three response to this point. The first response is to reiterate that economic models and our churn model can easily co-exist, having as they do quite different assumptions and foci.

A second response is that what one might well consider an apparent shortcoming of the churn model of knowledge value, its inability to provide precise quantitative indices for valuing discrete knowledge outputs, is in some ways its saving grace. By our concept, there no transitivity in knowledge value, no knowledge or technology that has manifest value apart from the idiosyncratic judgments of individuals. As an illustration, let us take a seemingly "obvious" blessing of technology. While there is currently much debate about the ultimate value of some medical technologies and even the previously sacrosanct goal of extending life, surely there is no quibble about the value of public health measures that increase the likelihood that persons in economically disadvantaged societies can have a biologically normal life span. But consider the case of one of the world's greatest inventions: indoor plumbing.

As reported in a recent newspaper article (*New York Times*, 1999)[8], a United Nations initiative to

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[8] Countless instances in the history of science underscore this point. One interesting recent case is *Science* magazine's rejection (without sending out for peer review) of breakthrough research on the cloning of laboratory mice. The editors deemed the research as of little interest to a general readership (as reported in *New York Times*, 21 July 1998).

provide indoor plumbing to impoverished villages in Bangladesh met with little success. *Even with full knowledge of the public health benefits*, the villagers had no wish to diminish the community bonding processes that occurred with the daily defecation and water gathering regime at a nearby river. The "obvious" advantages technology providing water not infested with deadly microbes was simply insufficient to trade for a lower quality of communal life. While this is perhaps an eccentric example, it nonetheless, makes the point that there is no knowledge or technology benefit that is of *obvious* value. The churn model does not even seek transitive values for knowledge and, indeed, implies that such a search is a false quest. In this respect, the measurement shortcomings of churn provide an advantage (in addition to clear disadvantage). The value of knowledge inheres in its repeated uses, the breadth of its uses and, particularly, its ability to create new uses: the "proof is in the putting". Knowledge not put to use has no value. We do not distinguish among uses simply because doing so requires equating intransitive values, such as "making money from a product" and "increasing understanding of the universe". Information that "fails" in one respect or another will not be used. Information will be untried, tried and discarded, or tried and transformed (thus creating value). The actual users of information and knowledge are the ones who, in practice, ascribe value. These values can sometimes be detected either in the compilation of uses indirectly observed (e.g. citations), direct testimony (e.g. interview data), or, as we suggest below, examining the fecundity of the KVC.

A third response to the issue of evaluating knowledge value has greater practical import for policy-makers. The churn model and its focus on KVC's requires one to attend to the social configurations of knowledge creation as the focus of evaluation. The question, then, is not "what is the value of knowledge products?", but "what is the value of social configurations for producing knowledge uses?" In many respects, the latter is a much more difficult question. But not one that is completely intractable.

6.3. Measuring knowledge value communities

Before evaluating a KVC, a first order task is operationally to define it. This is a daunting task in most cases, but so is it daunting to define research projects and programs, disciplines and fields (see Bozeman and Klein, 1999). The first task in the measurement of a KVC is to gather information about all the relevant connections among people through the use of scientific and technical information. Connections can be captured (and, ergo, collectives identified) in quite diverse, but complementary ways including highly detailed interview protocols, analysis of scientists' laboratory records, proposals, reports, diaries, and letters. It is here that well-developed social network approaches to mapping social capitals and social ties (e.g. Burt, 1997; Zucker et al., 1998) prove useful. Similarly, research value mapping (Kingsley et al., 1996; Bozeman and Kingsley, 1997; Dietz et al., 2000) an approach combining qualitative and quantitative identification of networks, can be employed in connection with the KVC.

Elsewhere, we have discussed in more concrete terms dimensions for an evaluation of the ability of KVC's to contribute to scientific and technical human capital (Bozeman et al., 2001) and to generate "translations", uses and applications for scientific and technical knowledge. While evaluation is not our chief concern here (for an evaluation study focusing on S&T human capital see Bozeman and Rogers, 2001), possible evaluation dimensions for assessing the KVC arc provided in an Appendix to this paper.

6.4. Policy implications of the churn model

Even before Crane's (1972) pioneering work on invisible colleges, most students of the social aspects of science and technology understood that knowledge rarely flows according to the organizational and institutional charts set forth by policy-makers and bureaucrats. A "federal laboratory" is an extremely rich admixture of resources and people (some "inside" the organization, some "outside") brought together to address scientific and technical problems (Crow and Bozeman, 1998; Niosi, 2000). The list of persons on the lab roster tells us little about the work and the connections among the workers. Likewise, a single NSF or NIH small science awardee provides a poor evaluation focus. The money provided to the grant recipient provides the opportunity for her to create new information, but it also funds graduate students (with effects quite significant and possibly distantly realized), provides equipment that others will share.

One of those students who participates in a "failed project" may learn a technical craft that will enable her twenty years later to produce new, fecund information that will give rise to multiple and widespread use.

Naturally, evaluation clients' patience wears thin waiting the twenty years for the agency-funded graduate student to produce the next great thing. But it is the very "event" focus of R&D evaluation that poses problems. It is not the "event" or the "article" or the "technology" or even the "market" that is the foremost concern, it is the capacity to produce these things and that capacity is embodied in knowledge value communities. It is here our evaluation tools must be plied. Institutions are important, but they are important because they affect communities. Institutions, programs and projects exist in the mind of bureaucrats and policy-makers and can be shuffled easily enough. Knowledge communities exist as human interactions with information. They are not shuffled so easily. It is easier to say "decommission the federal laboratories" or to wave a wand and say "this university is now in the research park business" than it is to conceptualize and support the KVC focusing on techniques for extracting and using genetic material from the drysophyla. But the most important policy lesson to remember when undertaking the daunting task of organizational and institutional designs is to not let them get in the way.

Because it is essentially qualitative, the churn model cannot compete with economic approaches in suggesting measures for value of the discrete output of scientific and technical knowledge. But that very qualitative nature also means there is no necessity for promotional bias in accounting for the impacts of knowledge and technology. Congressman George Brown's (1993, p. 415) decades of front-line experience with science and technology policy led him to a conclusion that accords with the underlying political tenor of the churn model: "technologies themselves have a profound impact on our daily lives, but it is fruitless to speculate on whether that impact is predominantly positive, negative or neutral".

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