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A use-and-transformation model for evaluating public R&D: Illustrations from polycystic ovarian syndrome (PCOS) research

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Abstract

Evaluating federally funded research and development (R&D) presents unique challenges to both federal science agencies and evaluators. Often focusing only on outcome evaluative measures (such as productivity or economic value) can shortchange the true value of the federal investment. For example, program directors at the National Science Foundation (NSF) and National Institutes of Health (NIH) talk about the “value added” of the new interdisciplinary science centers that they have funded—and they hope to be able to capture how funding can generate increased capacity for new cutting-edge research in the future. The purpose of this paper is to present a use-and-transformation model for evaluating public R&D, which explicitly focuses on measuring capacity-based metrics for evaluation instead of outcome-based metrics. The theory for the model presented here explicitly uses the concept of a Knowledge Value Collective that was introduced by Bozeman and Rogers [Bozeman, B., & Rogers, J. D. (2002). A churn model of scientific knowledge value: Internet researchers as a knowledge value collective. *Research Policy*, 31(5), 769–794; Rogers, J. D., & Bozeman, B. (2001). “Knowledge value alliances”: An alternative to the R&D project focus in evaluation. *Science Technology & Human Values*, 26(1), 23–55].

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1. Introduction

Until recently, serious discussions regarding the value of science were relegated to the safe confines of academic discourse. As long as Congressional committees, Presidents, and the general public were willing to take science’s value as a matter of faith or, at least, a proposition not worthy of deep reflection, questions of value and evaluation took on little urgency. In fact, science policy documents of the 1950s (President’s Science Advisory Committee, 1958, 1960; US Congress, 1986) gave the underpinning for the equation “science = technology = economic growth”.

During this time, the scientific community had little stake in questioning the economics of science equation—and policy-makers had little expertise or experience with those questions. While policy-makers and the general public remain enthusiastic about the promise of science, the naiveté of the first three post-war decades has now been

replaced with hard-won skepticism. For its part, a public that is now far removed from the war that “science won”, but not so far removed from technological disasters for which science often is held culpable, no longer seems to consider science as much different from other special interests competing for federal funds.

Among the many results of the changed social and political climate for science is a serious interest in evaluating science impacts, especially the impacts of publicly sponsored research and development (R&D). As part of the Government Performance and Results Act (GPRA) of 1993, science agencies, including those providing for the nation’s basic research, are required to give serious attention to evaluating impacts. One requirement of the GPRA is the submission of strategic agency plans to both the Office and Management and Budget (OMB) and Congress. The plans must 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, submission of these plans became routine. Moreover, these plans and measures are used in performance-based budgeting reviews

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1 and play a major role in the OMB's recommendations for
2 new budget allocations to agencies.

3 Additionally, in 2001 the Bush Administration intro-
4 duced the Program Assessment Rating Tool (PART)
5 because they believed that GPRA was not sufficiently
6 capturing outcomes. In particular, the PART review
7 analyzes factors that impact a program's performance in
8 a way that allows comparisons across time and similar
9 programs.¹ The goals of both GPRA and PART were to
10 make future funding decisions based on an analysis of past
11 program outcomes, yet it has been quite difficult to
12 demonstrate how this has worked in reality (United States
13 Government Accountability Office, 2005).

14 Given this increased focus on the evaluation of federally
15 funded R&D projects, it is more important than ever to
16 think carefully about an evaluation model that can capture
17 capacity building for public R&D investments. John
18 Marburger, the director of the US Office of Science and
19 Technology Policy, recently said that the traditional
20 indicators that have been used to evaluate R&D are
21 "based on a data taxonomy that is nearly three decades
22 old" (Marburger, 2005). The evaluation of publicly funded
23 R&D is an area where focusing only on outcome evaluative
24 measures (such as productivity or economic value) can
25 shortchange the true value of the federal investment.

26 For example, many NSF program directors talk about
27 the "value added" of the new interdisciplinary science
28 centers that they have funded. They want to see that these
29 centers are contributing more than just the sum of the
30 products of the individual researchers. In other words,
31 what do we (the federal government and individual
32 taxpayers) get by funding science centers that we cannot
33 get by funding the investigators individually? These
34 program directors are often looking for value added
35 through capacity building (i.e., the development of
36 capacity for new and innovative interdisciplinary research
37 after the center funding has ceased). As evaluators, we
38 cannot answer this question by focusing solely on
39 economic or productivity measures.

40 The purpose of this paper is to explore how the concept
41 of a Knowledge Value Collective (KVC) can be used within
42 a use-and-transformation evaluation model to measure
43 capacity building for federally funded R&D. Even though
44 the model could be applied to all sorts of public R&D, it is
45 most relevant for the evaluation of science centers (or
46 entities that encompass more than one individual research-
47 er). Before explaining the details of the use-and-transfor-
48 mation evaluation model, I will first describe the notion of
49 the KVC that has been introduced in previous papers.
50 Then, I will introduce the case of polycystic ovarian
51 syndrome (PCOS) research that is used to illustrate the use-
52 and-evaluation model in this paper. Next, I will present a
53 schematic of the KVC for PCOS research that I have
54 developed from 43 interviews with researchers in the
55

56 ¹For more information on the PART, see <http://www.whitehouse.gov/omb/part/>.

infertility field. Lastly, I will revisit the use-and-evaluation
model and flesh out the operationalization of this evalua-
tion model for public R&D.

2. The KVC

61 The concept of a KVC was first introduced by Bozeman
62 and Rogers (Bozeman & Rogers, 2002; Rogers & Boze-
63 man, 2001). They defined a KVC as a set of individuals
64 connected by their uses of a body of information for a
65 particular research application. Thus, the KVC consists of
66 knowledge producers and knowledge users who reshape
67 new scientific information into packages of knowledge *as*
68 *they use it*. Bozeman and Rogers (2002) argue that the
69 actual people making up the collective confer value to the
70 information that is generated by the KVC. If someone does
71 not use new scientific information that is generated by a
72 KVC, then there is no value to that information and it does
73 not become knowledge.

74 The use-and-transformation evaluation model that is
75 presented here uses the KVC of a scientific field as one unit
76 of analysis for the evaluation. Therefore, instead of
77 focusing on just one piece of funded research, the
78 evaluation model explores the development of new knowl-
79 edge within the funded research unit (e.g., university
80 research center)—and how that new knowledge is used
81 and distributed throughout the larger research community
82 (i.e., the KVC). This assumes that the value of knowledge is
83 best gauged by its use—and, thus, the value of a KVC (or a
84 unit within the KVC that is being evaluated) is best gauged
85 by its ability to produce new uses of information.
86 Traditional forms of evaluation research that focus on
87 bibliometric analysis or economics models of value often
88 ignore the extended network of knowledge users and
89 knowledge transformers that this evaluation model ex-
90 plicitly includes.

91 Following on work by Callon (1994) in particular, but
92 others (Crane, 1972; Elzen, Enserink, & Smit, 1996;
93 Liyanage, 1995; Rappa & Debackere, 1992) as well, this
94 model assumes that the terms "R&D project" and "R&D
95 program" fail to capture the inherent dynamism of the
96 interchange between work in funded R&D laboratories
97 and external influences and impacts of that work. Thus,
98 focusing an evaluation solely on the outcomes from a
99 funded piece of R&D builds an artificial boundary between
100 the micro-world of scientists and engineers and the macro-
101 world of other scientists and engineers, commerce, and
102 social institutions that use the science which was produced
103 by the researchers who were funded. By focusing the
104 evaluation efforts instead on the KVC, as well as the
105 contributions of the funded unit to the KVC, we can
106 measure the value that the funded unit has added to the
107 research community as a whole.

108 The crux of the argument for the use-and-transformation
109 evaluation model is that the best approach to valuing
110 scientific and technical information is to simply observe
111 repeated instances of its use—i.e., to map out the KVC and
112

the uses that come from the KVC. In other words, continued use and transformation of information is, in many respects, the best available index of value. The most common research evaluation approach—economic valuation—measures the value of individual or sets of uses. But in the case of federally funded R&D, strict economic valuation can “undercount” crucial uses of knowledge that have remote or no connection to markets and their pricing mechanisms. Certainly, some economics-based evaluation models have gone beyond the traditional focus on economic or productivity measures. For example, some evaluators have included a focus on additionality (Organization for Economic Co-operation and Development, 2006) or knowledge spillovers (Jaffe, 1996) when analyzing long-run impacts of R&D funding.

The use-and-transformation evaluation model takes a different approach by focusing not just on linkages among researchers, but, more broadly, on linkages among researchers, funding agents, research users, and the consumers of applications and technologies, including patients (for KVCs in medical fields). By focusing more broadly than researchers’ networks, evaluators are able to examine the dynamics by which other interacting components of the KVC affect research, research ties, and career trajectories. Also, they are encouraged to consider research impacts that are broader than publication counts, patents or citations.

Within the use-and-transformation model, the concept of value assumes that the *creation and valuation of knowledge are one in the same*—i.e., that information without use is information without value. Once put into use, information becomes knowledge and, at that point, has value. The appropriate “metric” for value is as diverse as the aspirations of users, including not only pricing and profits, but status, curiosity, and mastery of the physical world. By this concept, value becomes process: the constant development of knowledge and uses is what generates value.

Therefore, this model assumes that the development of new knowledge is bound together as value with the use and transformation of that new knowledge. The value of knowledge is established with its repeated uses, the breadth of its uses and, particularly, its ability to create new uses. In general, the use and transformation model cannot distinguish between uses simply because doing so requires equating intransitive values, such as “making money from a product” and “increasing understanding of the laws of physics”.² Most importantly, the evaluation model presented here assumes knowledge that does not have value will not be used—it will either be untried, tried and discarded, or tried and transformed (thus creating value through the transformation, but not through the original knowledge generation). Before delving into more details of

²Evaluators interested in making distinctions among incommensurate uses may wish to explore incorporating contingent valuation approaches here.

the operationalization of the use-and-transformation model, I will introduce the case that is used in this paper to illustrate the details of the KVC and the evaluation model.

3. The Case of PCOS

To further explain how an evaluator might go about defining a KVC—and linking it with the use-and-transformation evaluation model—I will explore these issues from the perspective of a case study. The KVC within the field of PCOS involves a diverse group of people, including basic scientists, clinicians, physicians, and women advocacy groups. Participants within each of the above-mentioned groups use and transform information into knowledge within the scientific field of PCOS research. For the study presented here, I conducted in-depth interviews with 43 researchers that work in the areas of reproductive science or infertility research. While most of these researchers worked solely in the area of PCOS, some researchers worked more generally in fields related to infertility research as well. All of the researchers that I interviewed were currently participating (or had participated in the past 10 years) in a reproductive science center funded by the National Institutes of Health (NIH). In particular, the interviewees were chosen because they were leaders in the field of the infertility research (in general) and PCOS research (in particular).

PCOS is the most common endocrine disorder in women of reproductive age (Wei & Pritts, 2003). The syndrome was first identified by Stein and Leventhal (1935) almost 70 years ago. Even though many think of PCOS as being a relatively common cause of irregular ovulation in women seeking infertility treatments, scientists learned in the early 1980s that PCOS is associated with a range of conditions that researchers have spent decades trying to agree upon (Kovacs & Burger, 2000). Currently, scientists studying PCOS largely agree that women with the syndrome generally experience one or more of the following symptoms: infertility or a higher risk of miscarriage, menorrhagia,³ amenorrhea or oligomenorrhea,⁴ hirsutism,⁵ anovulation,⁶ acne, male pattern hair loss, weight gain, insulin resistance and excessive androgen production (Adams, Polson, & Franks, 1986; Farquhar, 2000).

The PCOS scientific community recently made a distinction between “polycystic ovaries” (PCO) and “PCOS”. In other words, some women can have the characteristics of PCO (which is diagnosed using ultrasound methods) without demonstrating the biochemical changes or clinical symptoms of full-fledged PCOS (Kovacs & Burger, 2000).

³Defined as excessive menstrual bleeding.

⁴Irregular or complete cessation of menstrual cycle.

⁵Defined as excessive hair growth.

⁶Anovulation occurs when ovulation does not take place during the menstrual cycle.

1 Many more women have only one or two of the
2 manifestations that lead to a diagnosis of PCOS. Some
3 researchers have found that as the biochemical manifesta-
4 tion of PCOS becomes more severe, a woman is more likely
5 to have a clinical manifestation as well (Balen et al., 1995;
6 Conway, Honour, & Jacobs, 1989). Only recently have
7 scientists agreed that PCO can be diagnosed (via ultra-
8 sound) without any of the clinical manifestations of PCOS
9 (Polson, Adams, Wadsworth, & Franks, 1988). There are
10 clear benefits of using ultrasonic methods over direct
11 observation. Ultrasound allows for simple, non-invasive
12 diagnosis of PCO that does not damage the surface of
13 ovaries and potentially reduce fertility (as direct observa-
14 tion often does) (Farquhar, 2000).

15 The fact that PCOS is a hormonal disorder—marked by
16 the overproduction of male hormones called androgens—
17 explains some of the side effects of the syndrome, including
18 excess facial and body hair, male-pattern hair loss and
19 acne. Metabolically, PCOS is associated with insulin
20 resistance—or the inability of the body to efficiently
21 regulate insulin usage. Not surprisingly, as researchers
22 begin to recognize PCOS as both a hormonal and
23 metabolic disorder (Colino, 2004), they have started
24 linking the disorder to other types of diseases, including
25 diabetes, endometrial cancer, and infertility. Andrea
26 Dunaif, the chief of endocrinology at the Feinberg School
27 of Medicine at Northwestern University and Northwestern
28 Memorial Hospital in Chicago, has said that “whether the
29 reproductive disorder causes the metabolic disorder or vice
30 versa is still under investigation” (Colino, 2004).

31 The name of PCOS refers to the changes that the
32 syndrome often causes in the ovaries of affected women.
33 Women with PCOS will often have large ovaries that are
34 covered with fluid-filled cysts. But some researchers argue
35 that the name of PCOS is somewhat misleading. Dunaif
36 stated that “as many as 30 percent of women who don’t
37 have the disorder do have cysts on their ovaries” and the
38 name of the disorder encourages people to “focus on the
39 ovaries when this is a much more systemic disorder that has
40 metabolic consequences” (Colino, 2004).

41 Physicians and researchers are learning that PCOS is not
42 simply a reproductive disease; rather it is now thought of as
43 a systemic condition that possibly has a genetic component
44 (Kovacs & Burger, 2000). Hague, Adams, Reeders, Peto,
45 and Jacobs (1988) found that a high percentage of siblings
46 and mothers of women with PCOS have similar ultrasound
47 results when screened for PCO. Franks and colleagues
48 (Franks, Cela, Gharani, Waterworth, & McCarthy, 2000,
49 p. 23) say that while it is unlikely that there is a single cause
50 for PCOS, “it is likely that much of the clinical and
51 biochemical variability of PCOS can be explained by an
52 oligogenic⁷ pattern of inheritance, with the interaction of

55 ⁷A trait is considered to be oligogenic when two or more genes work
56 together to produce the phenotype. An oligogenic trait, which implies that
57 “few” genes are involved, should be contrasted with a polygenic trait,

environmental factors (notably weight) with a small
number of major causative genes”. 59

60 Although researchers have traditionally disagreed about
61 the diagnostic definition of PCOS, they often agree (to a
62 certain extent) about the prevalence of the disorder, with
63 most saying that PCO is much more common than PCOS.
64 Some researchers have estimated that up to 20 percent of
65 women may be affected by PCO (Clayton et al., 1992;
66 Polson et al., 1988), although not all of these women
67 display symptoms or are accurately diagnosed if they seek a
68 physician’s assistance. Other prevalence studies have
69 resulted in similar results. Three prevalence studies
70 conducted in the 1990s (Clayton et al., 1992; Farquhar,
71 Birdsall, Manning, Mitchell, & France, 1994; Michelmore,
72 Balen, Dunger, & Vessey, 1998) indicated a 16 percent to
73 23 percent prevalence of PCO among the female popula-
74 tion. Scientists tend to agree that the prevalence of full-
75 blown PCOS is much lower than the prevalence of PCO,
76 with PCOS affecting about 5–10 percent of premenopausal
77 women (Dahlgren & Janson, 2000).

78 Interestingly, the study of PCOS has evolved rather
79 slowly and physicians and researchers continue to struggle
80 to fully define the disorder and understand its underlying
81 causes. Farquhar (2000, p. 4) says that PCOS “is probably
82 the most common endocrine disorder in women, account-
83 ing for the majority of cases of hirsutism, menstrual
84 disturbance, and anovulatory infertility”. Yet, most of the
85 publications and randomized controlled trials in the field of
86 PCOS occurred after 1980 (Farquhar, 2000). Farquhar
87 (2000, p. 16) also explains that PCOS “is a subject that
88 continues to lead to an enormous amount of debate
89 amongst the medical and scientific communities”.

91 4. The PCOS KVC 93

94 The above discussion of the evolution of research in the
95 field of PCOS demonstrates that basic scientists, clinical
96 scientists and physicians have had to work closely together
97 to further the definition and understanding of PCOS. Basic
98 scientists have largely relied upon clinical trials to help
99 define the full range of the disease, while clinical scientists
100 have relied upon basic scientists to help them understand
101 the relationships between (and causes of) various manifes-
102 tations of the disorder. Physicians have also played a
103 significant role in the evolution of knowledge surrounding
104 the case of PCOS by taking information from both clinical
105 and basic scientists and transforming that into knowledge
106 that can be used to help individual patients. Given this
107 symbiotic relationship between these three groups, the
108 analysis of the PCOS KVC is particularly relevant when
109 planning for evaluation in this field. Traditional evaluation
110 methods (such as publication counts and citation rates)
111 cannot fully capture knowledge generated among and

(footnote continued)

which implies that many genes are involved in phenotype expression.
Source: PhRMA Genomics. 113

1 between the basic scientists, clinical scientists and physi-
2 cians in this case.

3 One senior researcher we interviewed explained that
4 there is a large community of clinicians and women who
5 use the results of the basic research that she generates in her
6 lab. This professor said that “hundreds of people ... use
7 my cell lines. That use changes PCOS research...Many
8 reproductive and infertility clinicians, as well as diabetic
9 treatment clinicians, [use my research]. Also, people with
10 patients with the disease”. She went on to explain how she
11 tries to make sure that the results of her basic research are
12 communicated to the larger public: “We have talks on
13 women’s health with the public. Also we outreach to the
14 PCOS community through their patient advocacy society
15 locally”.

16 The interviews conducted with PCOS researchers gave a
17 strong sense of the development of the research field that
18 addresses the syndrome. It was clear from the interviews
19 that many unknowns still exist within the field of PCOS
20 research—both in terms of what causes the disorder and
21 how one might “cure” it. One senior researcher explained
22 the complexity of the topic in the following quote: “If you
23 typed PCOS into MEDLINE you’d get many people.
24 From a clinical perspective it’s one of the most studied
25 conditions. It’s a complex and complicated industry too
26 and that gets people’s juices flowing”. Despite the fact
27 many of the researchers agreed that PCOS is widely
28 studied, many thought that it has not yet gained the
29 “celebrity” status of diseases like breast cancer.

30 By studying the case of PCOS research, I was able to
31 refine the analysis of how KVCs can be used to improve the
32 evaluation of science centers. There are several reasons why
33 the case of PCOS knowledge generation is an ideal case to
34 further refine the KVC framework developed by Bozeman
35 and Rogers.

36 First, the field of PCOS research is still being defined;
37 only within the last decade have scientists agreed (to even a
38 moderate degree) upon the diagnostic definition of the
39 disorder. Therefore, the case of PCOS allows us to view the
40 KVC evolution as scientists have tried to agree on
41 definitions of the disorder. At this stage in the development
42 of the field, there is a large amount of symbiotic interaction
43 between basic scientists, clinical scientists, physicians, and
44 women’s advocacy groups. Only after researchers in the
45 field of PCOS generated some common diagnostic defini-
46 tion of the disease could the community of the KVC be
47 defined. Before the diagnostic definition was defined (i.e.,
48 prior to the 1990 NIH conference), scientists and clinicians
49 who worked on research related to the biochemical and
50 clinical manifestations of PCOS (such as acne and
51 hirsutism) would not have been included in the KVC.

52 Second, the previous cases that Bozeman and Rogers
53 have used to describe the KVC concept have not focused
54 on medical or clinical fields. The case of PCOS research
55 allows us to observe how the nature of a KVC might be
56 different in the midst of the tension between basic science
57 and clinical trials—which is increasingly common in the

58 medical fields. When a science center includes basic and
59 clinical research there are a broad range of participants in
60 the KVC that cannot be identified by traditional evaluation
61 methods like bibliometric analysis. For example, in the case
62 of PCOS, if an evaluator tried to assess a reproductive
63 science center by assigning value only to publications that
64 were identified by bibliometric analysis, then any value of
65 knowledge that was generated and used in clinical trials or
66 by women’s advocacy groups would be ignored. Particu-
67 larly in the case of PCOS, it is important to measure value
68 of the knowledge generated by science centers as more than
69 just academic research publications generated by the
70 center.

71 So the KVC is made up of knowledge users who reshape
72 the information into new packages of information as they
73 use it. For example, a clinical scientist might take new
74 results of a basic science study that was conducted in a
75 laboratory environment and apply them to a new clinical
76 trial—thus, reshaping the basic science to make it relevant
77 for clinicians. Likewise, a physician might take scientific
78 results that are generated from a clinical study, transform
79 that knowledge, and use it to help individual patients. But
80 some knowledge uses and transformations are less obvious.
81 For example, those who purchased a fertility kit based on
82 PCOS research would not be part of the KVC (unless they
83 provided explicit feedback about this knowledge product).

84 The size of a KVC can vary from a (theoretical)
85 minimum of two to thousands or more. There is no
86 requirement that members of the KVC interact with each
87 other or that they are even aware of each other. Their
88 transformative use of scientific and technical knowledge is
89 what provides “membership” into the KVC.

90 Fig. 1 further illuminates the details of the KVC for the
91 field of PCOS research. The left three circles represent
92 communities of basic scientists (squares), clinical scientists
93 (circles) and physicians (triangles) who collaborate among
94 and between themselves to generate publications. Using
95 traditional evaluation methods, these publications would
96 be the only measure of value calculated as a result of
97 research undertaken by the three groups of knowledge
98 generators (the boundary for that value is highlighted by
99 the dotted-line oval).

100 When analyzing the value of the research from the
101 perspective of the KVC, however, the information gener-
102 ated by units of production (i.e., publications, patents, etc.)
103 is not considered knowledge until it is actually used by
104 some user community. Moving farther to the right in Fig.
105 1, we see that the information generated by the productive
106 output is converted into knowledge when it is used and
107 reshaped by the PCOS KVC. The KVC in this case consists
108 of basic scientists, clinicians, and physicians who use each
109 other’s information and, therefore, transform it into
110 knowledge. Then, knowledge generated by the KVC is
111 passed along to the PCOS user community who uses the
112 knowledge, but does not transform it.

113 Our interview data indicated that the PCOS user
114 community consists of one additional group that is not

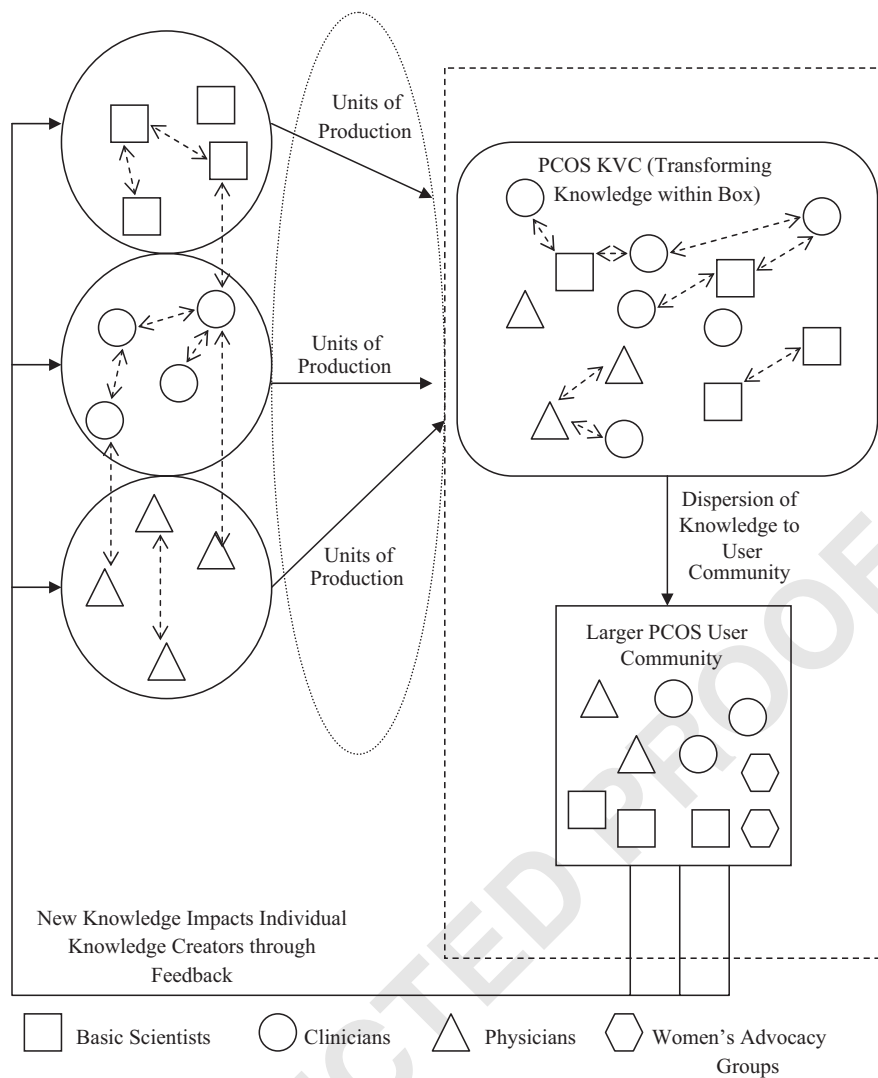


Fig. 1. Schematic of KVC for PCOS Case.

part of the KVC: women's advocacy groups. Since these groups use the knowledge, but do not transform or reshape it, they are not part of the KVC. If we used an evaluation method that focused on the PCOS KVC, we would measure the value of the research as the knowledge that is generated by the KVC. Also, we would value how the knowledge is dispersed throughout the user community (and utilized by the user community). This boundary is highlighted by the dotted-line rectangle.

Traditional forms of evaluation research that focus on bibliometric analysis would ignore the extended network of knowledge users and knowledge transformers that we find in the community surrounding the topic of PCOS. Within this community, we find many participants in the KVC who are not basic scientists and who do not publish basic science results that would appear in a bibliometric analysis—yet they use and transform knowledge that comes out of laboratories where basic scientists work.

Lastly, we can learn from the PCOS case that knowledge disseminated to the user community is often taken by basic scientists, clinicians, and physicians, and then combined with new information to generate new publications (which keeps the cycle moving along). It is through this feedback loop process (described by Fig. 1) that researchers in the field of PCOS have struggled to define an accurate diagnostic definition of PCOS.

5. Implicit assumptions in the use-and-transformation evaluation model

As previously mentioned, my goal in this paper is to introduce a new way of thinking about the evaluation of public R&D that incorporates an explicit focus on the relationships between the funded R&D unit and the larger research community. The goal of this is to capture the “value added” by the funding unit—while thinking of it as

part of a larger scientific community. I used the case of PCOS research in earlier sections to illustrate the concept of the KVC and the general approach of the use and transformation evaluation model. Next, I will turn to a more detailed discussion of how an evaluator might operationalize the use-and-transformation model. When appropriate I will use examples from the PCOS case to better illustrate the theoretical concepts introduced in the use-and-transformation evaluation model. But first, there are several implicit assumptions in the use-and-transformation evaluation model that need to be explicitly discussed before we talk about operationalizing the model. Each of these assumptions is outlined below.

5.1. The “equality of use principle”

A major assumption of the use-and-transformation approach to value is the *equality of use principle*. This principle stipulates that all uses of information are expressions of value to the user and, thus, the evaluator must resist placing higher value on some uses than others (observing only their repetition as an indirect indicator of reoccurring value). Using the PCOS KVC case as an example, this principle states that an evaluator would need to place the same level of value on the use of a basic science result generated within the KVC as s/he would on an applied science result generated within the KVC.

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. The quality of the output of research cannot really be a cause of its success because it cannot be assessed before it is picked up and used. Instead, the quality of research output is a result of its success among the relevant clients (e.g., published papers, hired students, adopted innovations). Therefore, the array of uses that reflect attribution of value of research output must be established empirically rather than imposed a priori. For example, in the case of basic research, journal publication citations are just one of a number of other possible indications of use of research outputs that become valuable as they are used.

The reader may at this point argue that this line of argument puts under-developed theories in the same category as articles published in *Science* or *Nature*. That is certainly possible within the use-and-transformation evaluation framework. In fact, this approach may sometimes put the under-developed design ahead of the scientific article. If nobody uses the scientific design and many use the under-developed design, the latter would be considered knowledge during the evaluation and the former would not.

5.2. The equality of media principle

If we adopt the assumptions of the KVC for the evaluation model—and we use the KVC as the unit of analysis—then productivity becomes a structural attribute

of communities, not an evaluative criterion. Productivity is the creation of information that may (or may not) obtain value (through future use or transformation). Since this evaluation model focuses only on use, not creation of knowledge independent of use, the answer to the question “What is productivity?” begins and ends with the question “What is used?” An information object that can be put to use by another is a “unit of production”. These units of production of scientific and technical information may be transmitted via any of the following media: scientific and technical articles, reports, electronic papers, lectures, demonstrations, technological devices, transmittable skills, technical processes, informal communications, popular media presentations, clinical trials, among others. So to bring this principle back to the PCOS case, the evaluator would need to place the same amount of value on the use of a peer-reviewed publication generated by a researcher in the KVC as s/he does on a physician using the result from a PCOS clinical trial.

Since value is attributed only in use within the model, the evaluation should not give a priori greater value to some media over others. So a brilliant idea presented for the first time in popular media has the same epistemological and practical meaning as one presented in a refereed scientific article. From a value standpoint, the key issue is the use of the information, not the medium through which the information is communicated. Citations, for example, are not information, but are footprints of use. Patents are not information (except for the patent application’s minimal description of the device’s technical information required to explain the technology), but rather are property devices. The evaluators will recognize that different fields of research (and, therefore, different KVCs) will select certain media over others and/or may shift from one medium to another depending on their strategies and the particular sort of information they produce.

Given all this, the use-and-transformation evaluation model can be adequately operationalized only if we adopt an *equality of medium* assumption. This assumption states that all media used to carry information outputs within a KVC are of equal value. For the operationalization of the use-and-transformation model, this means that the evaluators must document as many of the KVC information outputs as possible—and record their level of use. The predominance of certain media over others in the patterns of output of KVCs will be an important indicator of the strategies it pursues and the main emphases that characterize its work even though certain media outlets will not be assigned more value than others.

We can think about this assumption within the context of the PCOS case. After an evaluator documents all of the information outputs from the PCOS KVC, it might be clear that there is more output in the form of clinical trials than there is from peer-reviewed publications. If an evaluator found this result, s/he might be able to state that the PCOS KVC is more focused on applied research than it is on basic research. Additionally, documenting all

1 of the information outputs from the PCOS KVC might
 2 yield additional patterns about the preference of media
 3 within the KVC. But even though this finding might
 4 provide some interesting information for the evaluator
 5 (and the major funding agencies for the PCOS KVC), it
 6 would not allow the evaluator to place a higher value on
 7 either peer-reviewed publication outputs or clinical trial
 8 outputs.

11 5.3. Other assumptions

13 There are several additional assumptions that are less
 14 complex than the above two and, therefore, need less
 15 explanation. Third, the use and transformation model
 16 assumes that the knowledge users are the proper evaluators
 17 of the knowledge. The issue of quality of the knowledge
 18 products is decided when information is used to pursue
 19 new knowledge on the basis of previous findings. A fourth
 20 assumption is that the use of knowledge outputs is good
 21 and that more use is better than less use. Lastly, a fifth
 22 assumption is that a KVC that produces uses (and is able
 23 to “translate” others’ interests in terms of its own results) is
 24 superior to a KVC that does not produce uses or that
 25 produces non-repetitive, unique or dead-end uses. Now I
 26 will turn to operationalizing the individual steps in the
 27 model.

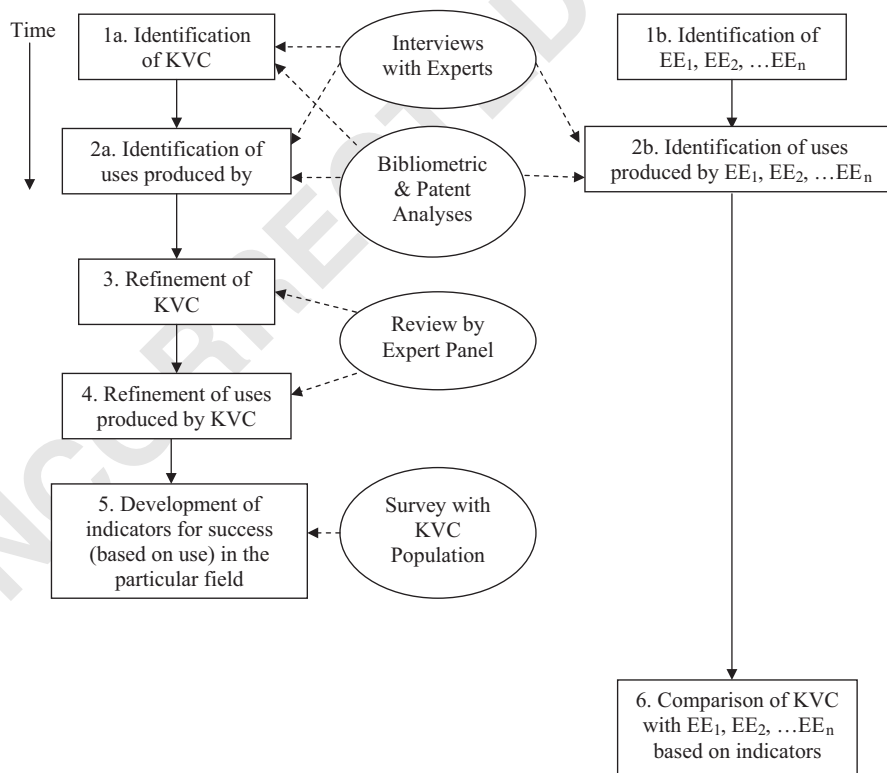
6. Evaluation steps for the use-and-transformation model

6.1. Defining the KVC

A process model for operationalization of the use and
 transformation evaluation approach is given in Fig. 2.

The first task in operationalizing this evaluation
 approach is the measurement of the KVC. To map out
 the KVC, the evaluators need to gather information about
 all the relevant connections among the researchers in the
 KVC field. These connections can be captured (and,
 therefore, communities identified) in quite diverse, but
 complementary ways, including highly detailed interview
 protocols, analysis of scientists’ proposals, reports, and
 publications.

First, in-depth interviews with key figures in the KVC
 will give the evaluators a broad sense of the contours and
 boundaries of the KVC. This is the process that was
 presented in Section 4 and Fig. 1 of this paper for the
 PCOS case. Next, the evaluators can use bibliometric
 methods to search among the different units of production
 (for example, articles, patents, or presentations) to fully
 define the members of the KVC. The first search for KVC
 members should be as inclusive as possible with a low
 threshold of relevance on indications of information use.



- Ovals represent methods used to inform tasks in rectangles.
- Rectangles represent milestones and/or tasks to complete during the evaluation.
- Dashed lines (---) indicate that the results of the method inform the step.

Fig. 2. Process model for the use-and-transformation evaluation approach.

1 For example, in the PCOS case, the first task for an
 2 evaluator would be to interview the major basic scientists,
 3 applied scientists and medical doctors that have worked in
 4 the PCOS area for an extended period of time. The goal of
 5 these interviews should be to allow the evaluator to define
 6 the general contours and boundaries of the PCOS KVC. In
 7 addition, these interviews should give the evaluator a sense
 8 of the range of media outlets that are used for distributing
 9 new knowledge that is created within the KVC. In the
 10 PCOS case, this would include (but is not limited to) media
 11 outlets such as peer-reviewed publications, non-peer-
 12 reviewed publications, clinical trials, conference papers/
 13 presentations, new diagnostic techniques for PCOS and
 14 PCO, and possibly new types of medication. Therefore, the
 15 goal of these initial interviews would be to outline the
 16 general boundary of the PCOS KVC. After the initial
 17 interviews are complete, the evaluator would use document
 18 analysis and bibliometric analysis of all media outlets
 19 described in the initial interviews to outline the more
 20 specific boundaries of the PCOS KVC. In sum, this search
 21 would outline all researchers, scholars and medical doctors
 22 who are part of the formal PCOS KVC.

23 The second task is to determine what sort of information
 24 has been generated within the KVC—and what types of
 25 information have actually been used. In particular, the
 26 evaluators should determine: (a) which uses are primary⁸
 27 and which are secondary⁹, (b) which uses are accompanied
 28 by formal arrangements such as grants and contracts, and
 29 (c) a full list of outputs over the known life span of the
 30 KVC and the relationship between the output and the
 31 KVC members (authorship, technical support, team
 32 membership, etc.). The information regarding KVC uses
 33 can be gathered through analysis of bibliometric data
 34 gathered from searchable media (i.e., literature reviews,
 35 patents, articles, conference proceedings, newspaper arti-
 36 cles). The searches of media should focus on research
 37 generated by each of the members of the KVC. The goal is
 38 to make this a comprehensive list that provides a snapshot
 39 of past and current uses at the date that the list is
 40 constructed.

41 Again using the PCOS case as an example, this step
 42 requires that the evaluator collect a full list of outputs over
 43 the known life span of the KVC. One efficient way to
 44 approach this process is to make a full list of the knowledge
 45 products generated by the researchers, scholars and
 46 medical doctors that were outlined as being part of the
 47 formal PCOS KVC in the previous step. Then, the
 48 evaluator can use bibliometric and document analyses of
 49 PCOS research to determine which of these KVC outputs
 50 has actually been used (and whether those uses are primary
 51 or secondary), as well as if the uses are accompanied by
 52 grants or contracts.

53
 54 ⁸“Primary” uses are those that reshape knowledge into new packages of
 55 information or technology.

56 ⁹“Secondary” uses do not reshape the knowledge, but simply take it and
 57 apply it.

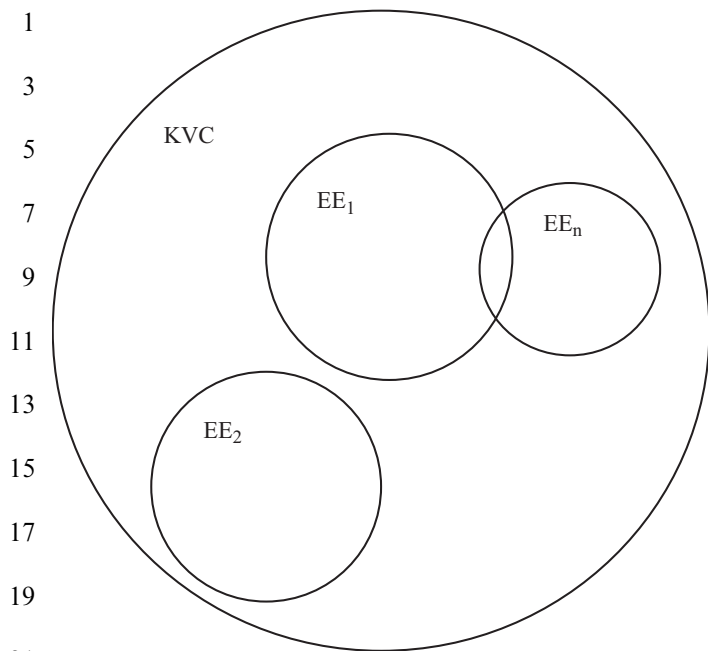
This approach provides the ability to study longitudinal
 changes in the KVC over time (and to compare different
 evaluation elements (EE) with the KVC at a later date).
 The results of the first and second tasks should lead to a
 preliminary identification of the KVC, its main transaction
 boundaries, its organizational and institutional relations,
 and a list of outputs and taxonomy of uses.

In the next step of the evaluation model, both the
 structure of the KVC (Step 1) and the identification of uses
 produced by the KVC (Step 2) are reviewed and refined by
 an expert panel. This expert panel should consist of 5–10
 key participants within the KVC. The main task for the
 expert panel is to determine if there are any holes in the
 mapping of the KVC structure (which was elicited in Step
 1) or the list of uses developed by the KVC (which was
 elicited in Step 2). In other words, as Fig. 2 shows, the
 expert panel refines the boundaries for the KVC and its
 uses. This expert panel should represent all aspects of the
 KVC. For example, in the case of PCOS research, it should
 include members of the following groups: basic scientists,
 clinicians, physicians, and women advocacy groups.

At the same time that the KVC is being identified, the
 EE that will be compared with the KVC can be identified.
 It is unlikely (although possible) that the unit being
 evaluated (i.e., the EE) will be the same as the KVC. In
 most instances, the unit being evaluated will be a science
 center or another cohesive unit that is funded by a public
 organization, while the KVC is the full network of
 scientists who conduct research in the field of interest.
 Therefore, rarely will the EE be the same as the full KVC.
 For example, in the case of PCOS research, the KVC is
 composed of the full network of basic scientists, clinical
 scientists, and physicians who are creating and transform-
 ing knowledge about PCOS, but the EE might just be one
 center that is funded by NIH to study PCOS. Therefore,
 usually the EE will be smaller than the KVC (see Fig. 3 for
 a typical schematic of the EEs in relationship to the KVC).

Since the EE(s) are outlined separately from the KVC,
 the structure of both the KVC and the EE(s) can be
 developed at the same time (as the time arrow in Fig. 2
 demonstrates). The boundary for the EE(s) will often be
 guided by the organization that is funding the evaluation
 research; in those cases, it will be easy to map the boundary
 of the EE. Also, as Fig. 2 demonstrates, the list of uses
 produced by the KVC can be developed at the same time
 that the list of uses produced by the EE is developed. In
 fact, it is probably easier for the evaluators to develop both
 at the same time because all uses produced by a KVC will
 naturally be linked to a producer—and that producer
 might be a participant in one of the EEs.

For example, within the PCOS KVC, the evaluator
 might be focused on the evaluation of a particular funding
 stream at the NIH. One possible example of this type of
 funding stream could be the U54 funding program titled
 Specialized Cooperative Centers Program in Reproduction
 and Infertility Research (SCCPR), which includes a strong
 focus on PCOS research. The first grants for the SCCPR



success) need to be developed. These metrics can be most accurately developed by asking the members of the KVC (i.e., experts in the field of research) to define them. Therefore, the full population of the KVC should be surveyed to elicit these indicators of success. In the PCOS case, the survey would be conducted with all PCOS researchers, scholars and medical doctors that are part of the formal KVC. Some of the survey respondents would be part of the SCCPRR program (i.e., the EE in the PCOS example), but many of the respondents would be external to that program.

It is important to note that this survey is not a “user” survey—i.e., it is *not* a survey aimed at capturing whether or not members of the KVC have used particular products developed by the EE(s). There is no need to conduct a separate “user” survey because the actual knowledge products do not make it onto the survey unless they have already been identified as having “value”—i.e., they have already been used.

Instead, the purpose of the survey is to inform the evaluators about the types of uses that are most common—and most reputable—within the KVC. This does not mean that the “equality of use” principle will be abandoned, but the survey does provide a way to uncover whether or not the EE has participated in the development of a use that receives an unusually high (or low) priority within the KVC. The survey should also be designed to capture additional success metrics, such as (a) growth variables, (b) human knowledge development variables, (c) social capital variables, and (d) resilience variables. In short, the purpose of the survey is to determine what indicators and measures can capture the *effectiveness* of the KVC—and, therefore, the effectiveness of the EE when it is compared with the KVC for evaluation purposes. Continuing our PCOS example, this means that the effectiveness of the SCCPRR program (i.e., the EE) would be captured by measuring how the SCCPRR program performs on these indicators—and comparing that with how the full PCOS KVC performs in those areas.

There are several advantages to evaluating the EE(s) by comparing them with the KVC. First, by its very definition, the KVC represents the “gold standard” for cutting edge research in a given area (i.e., there are a group of researchers competing with each other for leadership roles within that KVC and they are pushing the envelope in terms of technical development and expertise). Thus, one can assume that the leading researchers in the field are active participants in the KVC. Second, the use-and-transformation evaluation method can be repeated at a later date to show the respective growth (and change) of both the KVC and the EE over time. This allows for a very powerful longitudinal study of the EE’s changing role within the KVC over time.

6.2.1. Growth variables

Growth of the KVC is measured in terms of both uses and users. Thus, increasing “use” of products generated by

Fig. 3. Example of relationship between knowledge value collective and evaluation element(s).

program were awarded in April 1998—and there are currently 14 centers funded under this NIH program. These centers are located at the Baylor College of Medicine, Massachusetts General Hospital, Northwestern University, Oregon Health Sciences University, Stanford University, University of California-San Diego, University of Chicago, University of Illinois at Chicago, University of Kansas, University of North Carolina at Chapel Hill, University of Pittsburgh, University of Maryland, University of Virginia, and University of Washington.

If an evaluator was hired to evaluate the SCCPRR program for the NIH, the boundary for the EE would encompass all PCOS research at these 14 centers. Yet, the full PCOS KVC would be larger than these 14 centers (although it would definitely include all of the researchers, scholars and medical doctors participating in these NIH-funded centers). Therefore, in this case, the EE would be a subset of the larger formal KVC.

Another important point to make at this stage is that if the EE is a subset of the KVC, then it can often provide an ideal starting point for identifying the key experts who should be interviewed in the first step of the model (i.e., when the full KVC is being identified). Yet, the evaluator should be careful to ensure that if the key members of the EE are used to provide a broad outline for the full KVC (Step 1a), then the expert panel that is used to refine the KVC boundaries (Step 3) should also include key players who are not part of the EE.

6.2. Defining metrics of success for the KVC

After the KVC and its uses have been defined, then the metrics and indicators for KVC success (and, therefore, EE

the KVC means that the KVC is “growing”. There are two kinds of uses that the members of a KVC might employ: (1) the use of information developed by other KVCs (external to the one being studied in the evaluation) and (2) the use of information developed internally within the KVC. The ability to do both is important for the livelihood of the KVC. The most important uses for the evaluation, however, focus on the internal and external uses of the information that is generated by the KVC that is being studied for the evaluation. Therefore, the use-and-transformation evaluation model does not focus on uses that are generated externally; it only focuses on those that are generated within the KVC that contains the EE(s). For the PCOS case, this translates into a focus only on two types of information: (1) information that is generated by the PCOS KVC and used by members of the KVC and (2) information that is generated by the PCOS KVC and used by those who are external to the KVC. Yet, the evaluation would not focus on information that is generated by those who are not members of the PCOS KVC (even if members of the KVC are users of that information). This type of information does not contribute to the definition of the PCOS KVC because it was not generated within the KVC.

If the growth of a KVC is stunted, its potential for producing new uses and establishing new translations is also stunted. Therefore, the KVC life cycle depends entirely upon use. Naturally, measures of growth must take into account the developmental level of a KVC—i.e., different growth rates should be expected from emergent versus stable KVC configurations. So evaluators must consider not only the absolute size of the KVC and EE, but also the stage of development of both.

With slight adjustments in growth measures, the evaluator can capture different growth variables. If evaluators measure the *size* of a KVC (i.e., number of researchers within the KVC), then they can determine the *magnitude* of the domain (e.g., 50 uses). If they measure the *differences in growth* over a given period, then they can determine “base anchored” changes of magnitude (e.g., a shift from 50 uses to 100 uses). If they measure *rate of change in growth* (e.g., a 150% growth rate over 2 years), then they can capture a “base free” growth metric.

Each of these metrics is important and tells the evaluators something important to the evaluation of the EE. These values of magnitude (i.e., first differences in growth and rate of change of growth) can also be used to compare the EE to the “gold standard” (i.e., the KVC) during the evaluation. The below variables should be measured for both the KVC and the EE so they can be compared for the evaluation of the EE.

- *Absolute size*: Evaluators can measure the absolute size of the KVC by looking at the number of principal uses of information generated by the KVC-and the repetition of those uses.
- *Direction of growth*: Evaluators can measure the expansion or contraction of the KVC by exploring

changes in the magnitude of use over time. This gives the evaluators a sense of whether the KVC will become smaller or larger in the future.

- *Growth rate*: Evaluators can measure the rate of change in the growth or contraction rate to shed light on KVC life cycles.
- *Diversification of KVC use*: Evaluators can determine the diversification of the KVC use by comparing the number of uses that are external to the KVC to those that are internal to the KVC. Strictly speaking this would not be a measure of growth of the KVC itself, but it would indicate its ability to create value out of many sorts of inputs and the ability to provide diverse sources for others to create value.
- *Generative power*: Evaluators can measure the generative power of the KVC by analyzing its ability to spawn new KVCs (i.e., user groups which, while stimulated by the problem domain of the focal KVC, detach themselves and attack new problems enabled by work in the initial KVC). While it is not easy to measure precisely just when a new KVC has emerged from an old one, the birth of new KVCs can be captured through the survey of the KVC population.

As previously mentioned, the survey has two purposes in the evaluation: (1) to aid evaluators in prioritizing the quality of the uses generated within the KVC and (2) the computation of variables related to growth, human capital, social capital, and resilience variables listed below. With respect to growth variables, the survey should allow evaluators to determine which of the above growth variables are most indicative of success within the particular KVC being studied. For example, the members of one KVC might believe that generative power is more important than diversification of the KVC. On the other hand, members of another KVC might believe that diversification is more important than generative power. The survey allows external evaluators to determine the level of importance of each growth variable for the KVC population.

6.2.2. Human knowledge capital variables

An assumption implicit in the foregoing discussion, but which has not been stated explicitly, is that knowledge embodied in human beings is of a higher-order than disembodied knowledge contained in formal sources (e.g., technological devices, scientific papers). The reasoning is simple: information in formal sources is static and can be reconfigured only by human use and extensions. Knowledge embodied in humans is dynamic and subject to constant and immediate extensions and refinements with no intermediary-imposed (e.g., markets, publication delays) lags. The pre-eminent question for all KVCs is this: to what extent do they engender the building and flow of human knowledge capital?

One implication of this assumption is obvious: teaching, mentoring, skill development, “educational products”, and

1 student trajectories after leaving the research environment
 2 should not be a by-product for evaluators; they should be a
 3 core focus. While the production of breakthrough (i.e.,
 4 multiple use) scientific papers might be the benchmark of a
 5 previously successful KVC, the production of abundant
 6 human knowledge capital is an indication that the KVC
 7 has developed a capacity to produce future breakthroughs.
 8 Even though measuring human knowledge capital devel-
 9 opment is never an easy task, the key question in
 10 evaluating human capital development is this: what is the
 11 individual's ability, as reflected in the KVC, to develop new
 12 uses?

13 Unfortunately, this ability can only be ascertained after
 14 the use has occurred. Thus, evaluators can retrospectively
 15 determine (or at least provide good estimates of) human
 16 capital development by examining the KVC at a later date
 17 or by starting with uses and inferring human capital
 18 development in a reverse-time fashion. Depending upon
 19 the size of the KVC, it could be almost impossible to
 20 capture the full number of students, post-docs, and trainees
 21 involved in the KVC. Therefore, the human capital
 22 development variables listed below should be captured as
 23 average values that can be easily compared across the KVC
 24 and the EE(s). The values for the variables can be captured
 25 through the survey of the KVC population.

- 27 ● *Magnitude of human capital development*: Evaluators can
 28 analyze the average number of students, post-docs, and
 29 trainees that are mentored and funded by each
 30 researcher within the KVC and EE(s). These values
 31 can be compared across the KVC and EE(s).
- 32 ● *Impact of human capital development*: In addition to
 33 measuring the average number of students, post-docs,
 34 and trainees mentored within the KVC and EE (from
 35 the above variable), evaluators can also measure the
 36 impact of the KVC's investment in human capital
 37 development by analyzing the career trajectories of these
 38 students, post-docs and trainees.
- 39 ● *Changes in capacity for human capital knowledge
 40 development*: To capture changes in the capacity for
 41 human capital knowledge development, evaluators can
 42 measure the number of people entering and leaving the
 43 KVC and EE over time.

45 While the magnitude and change variables listed above
 46 can be captured through document analysis and the survey,
 47 the variable focused on "impact of human capital
 48 development" could be elicited via Curriculum Vitae
 49 (CV) analysis.¹⁰

51 6.2.3. Social capital

52 Human capital is not the only type of capital that
 53 successful KVCs build. Successful KVCs also contribute to
 54 the development of social capital both within (and external
 55

56 ¹⁰For details on analysis of Curriculum Vitae, see Bozeman and Rogers
 57 (2002) and Rogers and Bozeman (2001).

to) the KVC. While there are numerous ways to measure
 social capital, the variables that best capture the relation-
 ship between use and social capital are focused on
 measuring co-authorship and collaborations (in particular,
 the collaborations that involve use of information gener-
 ated by the KVC). The social capital variables of interest in
 the use-and-transformation evaluation model are listed and
 described below.

- 67 ● *Extent of co-authorship and collaboration within KVC*:
 68 Evaluators can measure the average levels of collabora-
 69 tion that take place within the KVC by studying the
 70 number of collaborations that use information gener-
 71 ated within the KVC.
- 72 ● *Extent of cross-KVC collaboration*: In addition to
 73 exploring the extent of collaboration internal to the
 74 KVC, evaluators can also measure the amount of cross-
 75 KVC collaboration that takes place (or the amount of
 76 collaboration that takes place both internally and
 77 externally of the EE).
- 78 ● *Extent of co-authorship and collaboration with graduate
 79 students, trainees, and post-docs internal to KVC*: Lastly,
 80 evaluators can measure the amount of collaboration
 81 that occurs between researchers within the KVC and
 82 their graduate students, trainees, and post docs. This
 83 variable is also linked to the previous notion of human
 84 capital development, but is designed to capture social
 85 capital development more explicitly than human capital
 86 development.

87 There are two well-defined methods that can be used to
 88 elicit the above variables: survey methodology and biblio-
 89 metric analysis. The survey that is conducted to determine
 90 the growth variables and human knowledge capital
 91 variables can also be used to elicit information from
 92 KVC members about their collaboration patterns. Survey
 93 questions would query KVC members about variables such
 94 as (1) the percentage of time they spend collaborating with
 95 researchers within their KVC field, (2) the percentage of
 96 time they spend collaborating with researchers in other
 97 KVCs, and (3) the amount of time they spend collaborating
 98 with trainees, students, and post-docs. Bibliometric analy-
 99 sis is a good way to supplement the self-reported
 100 collaboration data with actual co-authorship data.

101 As with the previous two groups of variables (growth
 102 and human knowledge development), the social capital
 103 variables should be elicited from both the KVC population
 104 and the EE(s). Then the variables can be compared to
 105 evaluate the performance of the EE with respect to the
 106 function of the KVC.

109 6.2.4. Resilience

110 A fourth group of variables that are important in the
 111 use-and-transformation evaluation model revolve around
 112 the concept of KVC resilience. Resilience can be defined
 113 here as the ability of the KVC (or EE) to remain intact
 through disturbances and changes over time. Therefore,

the resilience of the KVC (and the EE) can be measured by analyzing variables such as (1) age, (2) response to changes in the field (such as the development of new, contradictory science), and (3) length of time that individual members remain engaged. Each of these variables is discussed in more detail below.

- *Length of existence*: Evaluators can measure the length of existence of the KVC by locating the first uses of information generated by the KVC. This is the marker for the actual beginning of the KVC. Before this stage, the KVC might be in a development stage—and members might collaborate to use information from other KVCs. However, for the purposes of the use-and-transformation evaluation model, the KVC's start date is the date that the first piece of information generated within the KVC is used. The start date for the EE(s) should be much easier to determine since the EE(s) will typically be funded entities—with start dates that coordinate to the beginning of funding.
- *Rebound capacity*: A KVC's ability to rebound from internal and external changes (e.g., changes to the scientific field, personnel, and funding levels) can give evaluators a sense of the resilience of the KVC. In some cases, the KVC will be young and will not have experienced significant changes. Therefore, the previous variable (length of existence) is an important consideration when measuring the rebound capacity of the KVC or EE(s). In young KVCs, the rebound capacity might not be a measurable variable.
- *Extent of individual engagement*: While overall KVC (or EE) resilience can be measured with the above two variables, evaluators can also measure the resilience of individual membership in the KVC. The length of time that individuals participate in the KVC—and the prevalence of scientists leaving the KVC—can give evaluators a sense of the resilience of the individual participants within the KVC.

While the length of KVC (or EE) existence can be calculated through literature reviews and document analysis, the second and third variables can be captured through survey methodology.

7. Lessons learned

As with all evaluation models, there are limitations to the use-and-transformation evaluation model presented here. The first is that it is time consuming for evaluators to fully map out a KVC (and its uses) when the KVC has been in existence for a substantial amount of time. Second, as with all methods that involve survey methodologies, the model is dependent on a decent response rate from the sample being surveyed. Fleshing out the success metrics via a questionnaire does involve a certain level of respondent burden on the KVC population.

However, the use-and-transformation model (as presented) has some clear advantages over traditionally used evaluation approaches. Table 1 presents each of the three approaches to evaluation and provides a summary explanation, information about measurement approaches and assumptions, and apparent advantages and disadvantages.

As the table presents, there are some clear strengths and weaknesses to embracing a use-and-transformation evaluation approach. One weakness is that few people (and organizations) actually assume that all knowledge and uses are equal. Another weakness is that the method requires that the evaluators develop indicators of success for each KVC, which can require a significant time (and resource) investment.

With regard to the practical concerns of R&D evaluation, however, the use-and-transformation approach also has some practical advantages. In the first place, it attends to scientists' concerns that much that is of value in scientific knowledge is not captured as economic transaction. The KVC is that set of individuals connected by their joint use of sets of knowledge. Therefore, the KVC is composed of "primary" users of knowledge—primary in the sense that they reshape the knowledge into new packages of information or technology. "Secondary" users do not reshape the knowledge, but simply take it, whether learning scientific theory from a textbook (or the evening news) or using a technological device (i.e. physically-embodied knowledge).

Typically, the object of public R&D policy is *not* to support knowledge that will lead linearly to economic wealth. Instead, the objective is to develop capabilities and capacity. These capabilities and capacities are exercised through KVCs (Corley, Bozeman, & Gaughan, 2003; Dietz, Chompalov, Bozeman, Lane, & Park, 2000). Of course this evaluation model assumes that public R&D evaluation should center not on economic value or even improvements in state-of-the-art, but on the growth of capacity. A KVC approach has the practical merit of being well suited to the measure of capacity.

The comparison of advantages and disadvantages perhaps makes clear that the three approaches to understanding and measuring the value of scientific and technical output complement one another. Just as a triangulation approach to measurement sometimes offsets the measurement error associated with different techniques, so the use of multiple approaches to valuation has potential to mitigate weaknesses associated with the respective approaches.

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1 Table 1
Comparison of bases of science and technology valuation 59

3 Valuation basis	Description	Methods and measures	Advantages and disadvantages	61
5 Economic	Based on direct and indirect assessment of market value of output; focus on economic transactions and their precursors	Econometric, input-output models, cost-benefit analysis	<i>Advantages:</i> Precise measures, common basis of measures, intuitive appeal, makes scientific output commensurate with other outputs <i>Disadvantages:</i> Misplaced precision, inability to assess long-term impacts, overemphasis on “stock” versus “flows,” not equally amenable to all types of scientific output	63 65 67 69
13 State-of-the-art	Based on qualitative and quantitative indicators of output’s impact or potential impact on the growth of knowledge; focus on the artifacts of science and technology	Bibliometric techniques, peer review	<i>Advantages:</i> Construct validity of measures, future-oriented, substantive expertise of assessors, equality of use principle <i>Disadvantages:</i> Limited concern with extrinsic criteria, better for scientific output than technological output, limited reliability and criterion validity, equality of use principle	71 73 75 77
21 Use-and- transformation	Based on documented use of knowledge, range of uses, transformation of knowledge into new uses in new contexts; focuses on capacity building (i.e., capacity to create knowledge and new uses); focus on the “knowledge value community”	Analysis of knowledge value communities, network analysis, case studies, research value mapping; bibliometric techniques; in-depth interviews	<i>Advantages:</i> Dynamic, suited for both science and technology, future-oriented and focused on capacity-building, multiple dimensions of value <i>Disadvantages:</i> Less precision, noncomparability of uses (value), counter intuitive, measures/indicators of success require development for each KVC, defining the KVC may be difficult	79 81 83 85 87 89

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