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User community vs. producer innovation development efficiency: A first empirical study

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ABSTRACT

In this paper we report upon a first empirical exploration of the relative efficiency of innovation development by product users vs. product producers. In a study of over 50 years of product innovation in the whitewater kayaking field, we find users in aggregate were approximately 3× more efficient at developing important kayaking product innovations than were producers in aggregate. We speculate that this result is driven by what we term "efficiencies of scope" in problem-solving. These can favor an aggregation of many user innovators, each spending a little, over fewer producer innovators benefitting from higher economies of scale in product development. We also note that the present study explores only one initial point on what is likely to be a complex efficiency landscape.

1. Introduction and overview

Representative national surveys have established that millions of users in the household sectors of the U.S., Japan, and the UK spend billions of dollars per year in aggregate in order to create and improve products for their own use (von Hippel et al., 2011, 2012). Of course, it is also true that producers spend billions of dollars per year to develop products for sale *to* users.

Given the large scale of innovation by users, the relative efficiency of user vs. producer product development becomes an important matter. Practitioners would like to know whether innovation development or innovation adoption is more efficient for them. Efficiency also matters from a research and social welfare perspective. Expenditure of resources on low-efficiency innovation processes when better ones are available is wasteful, other things equal.

User and producer innovation processes are known to function very differently (Benkler, 2006; von Hippel, 2005). In fields of widespread interest, hundreds or thousands of product or service users may be innovating at the same time, and may make little or no effort to coordinate their development activities. Users each innovate primarily to satisfy their own needs. In contrast, producers innovate to sell *to* users. Producer development goals and activities are managed with the intention of efficiently developing products that are generally valued, and that are more desirable than competitors' offerings. New product development activities within producer firms may involve just a few developer employees.

On the basis of these rough descriptive outlines, one might speculate that user innovators as a class might be a great deal less efficient than producer innovators in developing generally-valued products. One can imagine, for example, that innovation projects engaged in by thousands of non-coordinating users could be directed at niche needs and/or could be hugely redundant. One might also reason that product developers employed by producers could have advantages over user innovators with respect to efficiencies related to specialization and economies of scale. Producer employees may, for example, have better product development skills than user innovators. They may also have access to much better R&D tools and facilities, justified on the basis of larger volumes of product development undertaken by firms.

On the other hand, it *may* be that in social activities like sports, and in the Internet age, user innovators are reasonably well aware of the innovation activities of others, and that redundancy of innovative effort is low. It may also be that the type of specialization that matters for efficiency in realizing some kinds of innovation opportunities is specialization in *use* rather than specialization in product development – and expert users may well have advantages over producers in that regard. Further, it may be that the diversity in problem-solving expertise present across a user community of thousands of solvers – what we term "efficiencies of scope" – may trump the depth of expertise of many fewer producer-employed solvers (Raymond, 1999; Jeppesen and Lakhani, 2010).

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Clearly, empirical studies of relative efficiencies are needed to understand these matters better. We begin this work by conducting a first empirical study of user vs. producer product development via a study of 50 years of product innovation in whitewater kayaking. In overview we find that in this field, users create important product innovations at a per innovation expenditure approximately 3× lower than that of producers. We also find that users tend to innovate early in this field, and producers tend to enter later as innovation opportunities in a field get "mined out" (Baldwin et al., 2006).

In what follows, we first review literature on user innovation and on innovation efficiency calculations (Section 2). We then describe the innovation history of whitewater kayaking, which is our context for this first study of user vs. producer innovation efficiencies (Section 3). In Section 4 we explain our research methods and data sources for information needed for our efficiency calculations. In Section 5, we present our overall findings, and in Section 6 we discuss the implications of these.

2. Literature review

2.1. Innovation by users

Consumer product development is now understood to be a major activity among citizens acting alone and in collaborative groups. Recently, three national surveys of representative samples of users over age 18 have explored the scale and scope of product innovation activities among users seeking to serve their own needs for new and modified consumer products. With respect to scale, these surveys found that millions of users collectively spend billions of dollars annually developing and modifying consumer products. In the UK, 2.9 million people (6.1% of the population) collectively spend $5.2 billion annually on this activity. In the US, 16 million people (5.2% of the US population) collectively spend $20.2 billion, and in Japan, 4.7 million people (3.7% of the population) collectively spend $5.8 billion to create and modify user products for their own use (von Hippel et al., 2012; Ogawa and Pongtanalert, 2011).

Studies of sporting enthusiast communities have found even higher rates of innovation, generally carried out collaboratively by community participants. Thus, Franke and Shah (2003) found 32% of members of four specialized sporting clubs in four 'extreme' sports had developed innovations for personal use. Similar results in additional sporting fields were found by Lüthje et al., 2005 (mountain biking); Tietz et al. (2005) and Franke et al. (2006) (kitesurfing), and Raasch et al. (2008) ('moth' boat sailing).

2.2. Innovation efficiency measurement

Definitions provided by the Oslo Manual (OECD/Eurostat, 2005) guide the collection of innovation-related data in OECD countries. Our definition of innovation adheres to the current Olso Manual definition – with an important caveat. Innovation, according to the Oslo Manual, is the introduction of a new or significantly improved product *to the market* or the use of new or significantly improved processes (transformation and delivery, organizational change and business practices, and market development). In this study of new products, producers do diffuse products via the market, as fits the Oslo definition of innovation. However, diffusion of new products developed by users often does *not* involve the market. Instead, diffusion is accomplished via peer-to-peer sharing of the product within a community of practice or peer group. For example, open source software also is diffused peer-to-peer instead of or in addition to diffusion via the market. This non-market mode of diffusion is increasingly commonly encountered (Baldwin and von Hippel, 2011). In the light of this finding, Gault (2012) proposed to update and broaden the Oslo definitional requirement that to be an innovation, something new must be 'introduced on the market' (OECD/Eurostat, 2005: 47). He suggests a broader condition – that an innovation must be 'made available to potential users', whether via the market or other channels. In this paper, we use the broader definition proposed by Gault, and include novel products diffused peer-to-peer and/or by the market as innovations.

In economics, efficiency is generally measured according to the value of resources (inputs) that are expended to create a given output. If the output being created is an innovation then, other things equal, the more efficient process will be the one that uses fewer inputs to produce that output. There are many types of inputs to innovation development that are recognized as important (OECD/Eurostat, 2005: 36). In the European Union Community Innovation Survey (CIS) 2010, expenditures are collected for four innovation activities, in-house R&D (OECD, 2002), purchase of external R&D, acquisition of machinery, equipment, and software, and acquisition of external knowledge. In the study reported upon here, as will be detailed later, included expense categories are considerably more restricted: we focus only on direct product development time and money investments by user and producer innovators.

2.3. Innovation efficiency and problem-solving economies of scale

Increased specialization is assumed to be associated with increased efficiency, and is made possible by the scale of the market (Stigler, 1968). Thus, economies of scale in production are associated with such things as increased specialization of workers, and the increased specialization of tools and equipment that larger scale production can justify.

Efficiency in problem-solving is also assumed to be positively affected by scale. For example, larger-scale R&D organizations can presumably afford to hire more specialized and expert researchers, and also can economically justify more specialized equipment for these employees to increase problem-solving still further. The expertise of specialized problem-solvers can indeed lead to greater efficiency, but deep specializations can at the same time narrow scope of solutions considered. Expertise in problem-solving is gained through repeated experience with respect to a particular type of problem and solution type. It has been shown that chess masters, for example, are much faster than less-skilled players at analyzing the strategic options available in a particular state of play and finding a good solution. They achieve this higher level skill and speed in problem-solving by long experience in the game. However, their better problem-solving performance is also quite narrow: when the rules of the game are changed, their performance is no better than that of those with lesser expertise (Chase and Simon, 1973; Gobet and Simon, 1998).

Classic studies of problem-solving also build our understanding regarding the limitations associated with expertise. Due to an effect called "functional fixedness," subjects who use an object or see it used in a familiar way are strongly blocked from using that object in a novel way (Duncker, 1945; Birch and Rabinowitz, 1951; Adamson, 1952). Indeed, the more recently subjects observe objects or problem-solving strategies being used in a familiar way, the more difficult they find it to think of employing them in a novel way. Thus, it has been found that experimental subjects familiar with a complicated problem-solving strategy are unlikely to devise a simpler one when this is appropriate (Luchins, 1942). The restrictions associated with expertise are also visible in real innovation settings. Thus, Allen and Marquis (1964) found that the success of a research group in solving a new innovation-related problem depended on whether solutions it used in the past fit that new problem.

In sum, if the problem-solving personnel in the development departments of producers follow the general pattern just described, then we can expect that the firms will display expertise within a narrow range of problem and solution types – but perhaps be no more expert than novices outside that range.

2.4. Innovation efficiency and problem-solving efficiencies of scope

We next consider potential efficiencies of *scope* with respect to solving a given problem. By efficiencies of scope, we mean the economies potentially achievable by asking many people with diverse problem-solving skills and types of expertise to identify problems and/or solutions. The restrictions to familiar solution types that each potential solver experiences, described in the previous section, suggests that a wide diversity of solvers – more likely to be present in a user solver community of thousands or tens of thousands than in a producer solver community of tens or hundreds can lead to problem solving efficiencies.

Raymond (1999, p. 31–32) described the problem identification and problem-solving advantages associated with bringing the problem to the attention of a broad range of potential solvers. He dubbed the phenomenon Linus' Law, and described it within the specific context of finding and fixing bugs in open source software code.

"Given a large enough beta-tester and co-developer base, almost every problem will be characterized quickly and the fix obvious to someone... "More users find more bugs because adding more users adds more different ways of stressing the program. This effect is amplified when the users are co-developers. Each one approaches the task of bug characterization with a slightly different perceptual set and analytical toolkit, a different angle on the problem... So adding more beta-testers may not reduce the complexity of the deepest bug from the *developer's* point of view, but it increases the probability that someone's toolkit will be matched to the problem in such a way that the bug is shallow *to that person.*"

Efficiencies of scope are more realizable today than has been the case in the past. In the Internet age, it is practical and low-cost to ask many potential solvers to contribute to a solution by simply posting questions on appropriate sites. Indeed, this approach is now practiced increasingly widely in the form of tournaments and contests inviting any who wish to attempt to solve a problem posed by the contest operator. Jeppesen and Lakhani (2010) have documented the potential value of scope of expertise in a study of winners of contests sponsored by the firm Innocentive. They found that, often, contest winners drew upon types of expertise to solve a problem that were quite different from those that might have been assumed in advance to be useful.

3. Case study innovation history

The main challenge in comparing the relative efficiency of communities of users at developing innovations with the efficiency of producers lies in the collection of reliable data on the innovation activities of and expenditures made by thousands of widely distributed users. To ease these difficulties in a first exploratory study, we decided to focus on a single user field with an innovation history that had previously been carefully researched and documented by Hienerth (2006) – the sport of whitewater kayaking. In this section, we briefly describe this sport and its innovation history.

Whitewater kayaking began over 50 years ago, and it has grown significantly in scale over the years. It is now practiced worldwide, wherever suitable whitewater sites can be found. In the mid-1970's whitewater kayaking "enthusiasts" within the U.S. (defined as those taking more than 5 whitewater kayaking trips per year) numbered only about 5000 individuals (Taft, 2001). Worldwide, the outdoor industry participation study (Outdoor Foundation, 2009, 44) finds around 1.2 million people paddling in whitewater in 2008, representing about 15% of all paddling activities. Using data from the Outdoor Industry Foundation (2006) and the Outdoor Foundation (2009) our conservative estimate of direct and indirect expenditures on whitewater kayaking worldwide (expenditures by participants for gear and travel and other services) is $1–2 billion annually.

The innovation history of whitewater kayaking was obtained from the writings of and interviews with several experts with deep and long-term experience in the field. These experts were: Susan Taft, author of the definitive history of whitewater kayaking (2001); Kent Ford, a filmmaker who has created several historical documentaries on whitewater kayaking (2009); Jackson (1999, 2000) head of today's major kayak-producing firm, Jackson Kayaks, and four-time whitewater champion kayaker; Corran Addison, a former whitewater champion, and also a serial entrepreneur in whitewater kayaks and surf equipment (founder of or designer active in Savage Designs 1994–1996, Riot 1996–2003, Imagine Surf 2002–2012); two long-time editors of the major whitewater kayaking journals.

According to these expert sources, the innovation history of whitewater kayaking can be divided into four phases, two of which occurred in parallel.

3.1. Phase 1

In the earliest innovation phase (1955–1973) kayakers initiated and began to develop the sport by exploring how to maneuver their boats in progressively rougher whitewater. To accomplish this, they developed and built novel equipment for themselves, such as shorter, more maneuverable kayaks made of fiberglass. They also developed novel paddling techniques. These new or significantly improved kayaks and techniques were shared in the community via peer-to-peer diffusion. In the beginning of this phase, no manufacturer commercially produced whitewater kayak designs. However, with the community of whitewater kayakers growing, some individuals started making copies for their peers at local kayak clubs. That lead to the emergence of small companies that basically supplied local markets. These manufacturers copied successful designs that had been developed by users and sold them to users who did not want to build their own fiber glass kayak.

3.2. Phase 2

In the second phase of whitewater kayaking innovation (1973–2000), innovative kayakers continued to develop novel kayak hulls in fiberglass. As the sport moved to the challenges of progressively rougher whitewater conditions, it became apparent that whitewater kayaks made of fiberglass were too easily damaged. In 1973, Hollowform followed by others, solved this problem by producing user-developed whitewater kayak designs in polyethylene. Along with a new manufacturer (Perception) founded by a former whitewater kayaker Bill Masters, these firms introduced mass production, professional distribution channels, and advertising. As a result, production and sale of whitewater kayaks rose by a factor of 100 during phase 2.

Once equipped with durable polyethylene kayaks, kayakers developed new whitewater maneuvers that involved intentional rough contact with obstacles in the river rather than avoiding them. For the first time, for example, dropping down significant waterfalls and encountering associated major impacts with rocks became feasible and part of the sport. Information on novel techniques was shared peer-to-peer – companies were not involved in diffusion of this type of innovation.

3.3. Phase 3

The third innovation phase ran partly in parallel to the second. Starting in 1980 and extending to 1990, a small group of kayakers ignored the mainstream whitewater activities involving plastic kayaks, and began instead to develop and experiment with very low buoyancy "squirtboat" hull designs that they made from fiberglass. Because of the low buoyancy of these designs, innovating kayakers were for the first time able to push their boats entirely underwater with their paddle strokes. They could then develop new techniques and engage in "three dimensional" (3D) maneuvers both under and on the surface of the water. A significant practical drawback to the squirtboat designs was that they were not suitable for mass manufacture. Squirtboats were designed to have only a few pounds of net buoyancy, and so each boat had to be tailored to the weight of the kayaker who would use it. During that period only two manufacturers supplied small numbers (around 1000 copies per year) of hand-laid up fiberglass copies of squirtboats based on designs developed by users.

3.4. Phase 4

The fourth phase of whitewater kayaking innovation began in about 2000 and continues through 2012. This period began with the finding that one could do many of the 3D maneuvers developed by squirtboaters by coming up with novel hull designs that increasingly concentrated buoyancy in the center of the boat, while retaining the minimally buoyant bows and sterns characteristic of squirtboat designs. Kayakers using what came to be called rodeo kayaks were able push the ends of their boat underwater with paddle strokes in order to do end-to-end flips and other new 3D maneuvers. At the same time, these new hull designs were considerably safer due to their higher net buoyancy, and could be mass produced from durable plastic rather than custom made for each paddler from fiberglass.

Most whitewater kayak producer firms were founded by users who were highly skilled kayakers, and often winners of many whitewater kayaking competitions. Eric Jackson and Corran Addison, expert interviewees and discussants on this research project, fit that mold. They were both champion kayakers, and started their own companies in order to incorporate their novel ideas derived from use experiences into innovative kayak designs.

4. Research methods and data sources for efficiency calculations

In this section we explain the component analyses needed for our efficiency calculations, and explain how we collected each type of data needed.

In overview, very valuable resources for all of our data collection work, beyond the continuing help from the experts identified in section 3, were access to the complete database of magazines, descriptions, and photos published by the American Whitewater Affiliation since 1955. The annual "gear issue" of Canoe and Kayak Magazine, produced each year since 1975, was an especially helpful resource.

In addition we conducted an online survey of innovating kayakers. Our online survey of present and former whitewater kayakers was designed to collect data on user innovation processes, expenditures, and motivations for each innovation phase of whitewater kayaking's history. We obtained complete survey responses from 201 respondents who reported innovating in kayaking equipment. Respondents were coded as "innovating" if they responded affirmatively to a question asking if they engaged in designing and building novel hardware/equipment for their own use in whitewater kayaking such as kayak hulls, hull modifications, kayak fittings, equipment, safety vests, paddles, rescue rope, etc.

Our goal was to survey kayakers who had been active from the earliest period of the sport in the 1950's to those active today. To achieve this, we spread awareness of our survey among potential respondents in multiple ways. First, with permission, we posted the survey on the websites of the major whitewater kayaking organizations in the US (American Whitewater) and Europe (Playak). In addition, the survey was available on an independent server (kayak-innovation.org) for a three-month period. We also contacted large kayak clubs and organizations (e.g., American Whitewater Freestyle Association, Deutscher Kanuverband) and a firm with a large online network (Jackson Kayaks), and asked them to inform their members about our project and questionnaire.

Information posted online was expected to primarily reach more recent participants in the sport. This proved to be the case: 57% of respondents to the web-based versions of the survey had their most active decade in the sport in the periods after 2000. We anticipated that kayakers who were active in the 1950's and 1960's would be less likely to use the web than those in more recent decades. To obtain as many respondents as possible from this era as well, we asked Sue Taft, whitewater kayaking historian and author, to contact her network from the early days, either sending kayakers a personal email containing the survey, and/or sending a hard-copy version of the survey via physical mail. The result of this outreach was 15 additional respondents, 14 of whom had the starting year of their most active period before 1980. Six of these respondents had the starting year of their most active period before 1960, giving us useful additional insight into the very beginnings of the sport.

It is likely that the innovators who responded to our outreach and answered our survey were more engaged in the sport than the average innovator, and so might have spent more time and money innovating than the average innovating whitewater kayaker. This possible selection bias would skew our findings in a conservative direction with respect to a finding of high innovation efficiency by users by overstating the level of innovation expenditure in the user community. We discuss this matter, along with other possible sources of bias in our data, in Section 6.2.

4.1. Number of producer and user innovators

In order to compare the efficiency of producer vs. user innovations, we needed to determine how many innovating producers and users were active during each of the four phases of whitewater kayaking.

We identified whitewater kayak producers extant in the four phases of the sport's history by searching for advertisements in the files of whitewater kayaking journals. We also searched online databases (e.g., Manta and Zoom Info) for information on smaller and medium sized manufacturers. We used the Orbit and Compustat database for identifying and getting key information on larger manufacturers or holding companies (e.g., Confluence Holdings Corp.). (As is common in extreme sports, whitewater kayakers who make equipment for themselves may also sell or give away a few handmade copies of their innovations as a supplementary source of income, or as favors for colleagues (Shah, 2000). We included such users as users, defining our kayak producer sample as consisting of incorporated firms only. As a result, our user sample fits labor statisticians' definition of the "household sector" of the economy: The household sector is defined as comprising individuals in all resident households and also includes their unincorporated enterprises (Ferran, 2000; Resolution ICLS 1993; Hussmanns, 2003)).

We sent emails to all owners of extant and now discontinued companies in the field to determine their dates of activity and their incorporation status when this information was not otherwise available. The total number of incorporated whitewater kayaking

Table 1
Number of user and producer innovators in whitewater kayaking.

Innovation phase	Whitewater kayakers (Worldwide total)	User innovators (Number at start → and end of phase)	Producer Innovators (Number at start → and end of phase)
Phase 1 (1955–1973)	0 → 10,000	1 → 2500	1 → 8
Phase 2 (1974–2000)	10,000 → 800,000	2500 → 4000	Fiberglass kayaks 8 → 20 Plastic kayaks 2 → 10
Phase 3 (1980–1990)		1 → 1000	Fiberglass kayaks 1 → 2
Phase 4 (2000–2010)	800,000 → 1.2 million	4000 → 6000	Fiberglass kayaks 3 → 6 Plastic kayaks 10 → 15

producers, worldwide, extant at the start and end of each innovation phase is shown in Table 1.

Estimates of the number of users – whitewater kayakers – active in each phase of the sport, and the proportion of these likely to be innovators started with literature and online research by Hienerth to identify whitewater kayaking clubs active in the four phases of the fields and other related information. This information was then discussed and refined with the whitewater kayaking experts described earlier, and with various club members identified by Hienerth during his research on this matter. It is reasonable that expert whitewater kayakers would be widely knowledgeable about the scale of kayaking groups internationally. Due to the nature of the sport, enthusiast kayakers often travel to and network at events held at especially good whitewater kayaking sites around the world.

4.2. *Sources of important equipment innovations*

Our next step was to identify the important equipment innovations developed by users during the 55-year history of whitewater kayaking. Based upon the advice of experts in the field, we did this by first searching the complete archives of magazines, descriptions, and photos published by the American Whitewater Affiliation since 1955. As was noted earlier, the annual "gear issue" of the Canoe and Kayak magazine, produced each year since 1975, was an especially helpful resource. All equipment innovations described as interesting, important, or significant in this literature over 50+ years were identified, resulting in an initial sample of 128 innovations. To focus our sample on innovations of functional value, we removed innovations that were of esthetic value only (e.g., user development of more stylish helmets).

We next asked the four earlier-mentioned experts with long-term experience in the history of the field – Susan Taft (2001), Kent Ford (2009), Corran Addison, and Eric Jackson (1999, 2000) to filter and amend this initial list. The availability of the list served as cues to these experts to make additions as well as subtractions. For example, the American Whitewater Affiliation Magazine described an emergency rope added by users to their kayaks to be used to help tow fellow kayakers out of trouble. Our experts then noted an important follow-on innovation – the introduction of a safe and quick release mechanism to uncouple the boats again as needed – quick decoupling is sometimes essential. A final review by our experts produced our final list of 108 innovations (see Appendices A and B for complete innovation listings by phase and source).

The same sources of information used to identify our sample of innovations was also used to identify the developers of each. For producer firm-created innovations, originating firms were often noted in the description, and known to our historians as well. In the case of household sector innovations by users, a specific user innovator was often not identified. This is reasonable because innovation process information in our survey data shows that 74% of user innovation activity in this field is collaborative and that over 90% is open, with innovators freely sharing their design information for adoption by others. Shared co-creation of innovations by users and producers also occurred. If the users were compensated, the innovations developed were coded as producer innovations. Shared co-creation with *un*compensated users was quite rare according to our expert interviewees.

4.3. *User innovation expenditures*

In our survey questionnaire, we asked respondents whether they had innovated by modifying or creating equipment they used in whitewater kayaking. Those who answered affirmatively were then asked about the amount of money and time they spent annually on their kayak-related product development activities during their most active decade in the sport. We asked about direct product development expenditures only. In other words, we did not ask about rental of design space, acquisition of capital equipment, etc. This omission in the case of user innovators was reasonable. Our interviews with innovating users, and discussions with our experts as well, made it clear that innovating individuals did not rent space or buy expensive capital equipment to pursue their hobby. They developed their innovations in their basements or garages, using tools they had on hand or cheaply purchased.

To obtain annual aggregate user innovation expenditures for each phase of the sport, we averaged the annual expenditures reported by survey respondents active in that phase and multiplied by the average number of innovators in the phase (Table 1).

We converted user time expenditures to money using the minimum US wage for each specific whitewater kayaking innovation phase times the average number of innovators active in the respective phase (from Table 1). These figures were then converted to 2012 dollars. In the earliest phase, minimum wage is probably a low estimate of the value of user innovator time. Historians of the sport tell us that many of the earlier innovators were young to middle-aged engineers or other specialists who presumably commanded higher wages. In later phases, young athletic males came to be a large portion of the most advanced practitioners of the sport, and for them the minimum wage calculation is probably on target.

4.4. *Product development expenditures by producers*

Data on kayak producers' expenditures on product development was obtained from two types of sources. First, two historians of whitewater kayaking, Taft (2001) and Ford (2009), provided information from their writings, interviews, and recollections. Second, we conducted interviews specifically devoted to product development costs with CEO's and product development managers of present and former producers of whitewater kayaks in the business sector.

As will be seen in Table 5, in each innovation phase except phase 1, the producer industry consisted of one or two large firms plus a number of smaller firms. Discussion with managers of both large and small firms showed a product development process that was very similar to that carried out by individual users. Designs would be developed on paper blueprints or, later, on portable computers. Prototypes would then be constructed out of fiberglass and plastic resin, and they would be tested and iteratively refined by actual use in whitewater conditions.

As was the case in our collection of data on user expenditures, the expenditure data we sought from producers was labor and materials utilized for product design, prototyping and testing only. Capital expenses for the product development operation like buildings and major tools were excluded, and so biased in favor of producer innovation efficiency. This is appropriately conservative with respect to our study findings of higher user than producer innovation efficiencies. Also, since we are comparing only product development expenditures by users and producers, producers' expenditures on such things as production tooling, and their expenditures on marketing and sales were also excluded.

We computed producer expenditure totals by first drawing in Table 1 to determine the average number of large and smaller business sector enterprises extant in each innovation phase. We then multiplied the number of each type of firm times the average annual product development expenditures for that type of firm in each phase. Product development expenditure data from smaller firms we were able to contact was averaged, and assumed to be representative of all smaller firms in our sample.

We adjusted all expenditures to 2012 dollars, then added together total large and smaller firm yearly expenses, and multiplied times the number of years in each phase to derive the total business sector product development expenses for each phase. The resulting business sector product development expenditures for each phase and for all phases taken together, adjusted to 2012 dollars, as will be shown in Table 4 (U.S. Department of Labor user price index, 2012).

5. Findings

We next turn to our findings regarding relative user vs. producer efficiency in the development of important product innovations in the field of whitewater kayaking.

5.1. Number of active user and producer innovators over time

In Section 4.1 we described the data collection sources and methods used to determine the number of innovating users and producers active in the field of whitewater kayaking over time. Our findings on this matter are shown in Table 1.

Note from Table 1 that the level of user innovators in each successive phase in the innovation history of the sport does not simply rise monotonically, even though whitewater kayaking was progressively more widely practiced. This is because the conditions for and difficulty of user innovation differ in each *innovation* phase of the sport. Thus, in phase 1, both user-made and commercial kayaks were constructed from fiberglass, an easy and inexpensive material for users to work with. About 50% of all active kayakers were estimated to be developing at least minor innovations in that early phase by our experts. Equipment was rapidly evolving, and most kayakers 'built their own' rather than buying commercial equipment. When building, they would often devise modifications for their own use.

In phase 2, most producer-made kayaks were made from rotationally molded plastic, and these were very difficult for users to modify–with the result that a smaller number of users were innovators. Those who did innovate either continued to work in fiberglass as in phase 1, or made add-ons to plastic kayaks. In phase 3, as was mentioned earlier, "squirt boats" were very difficult for less-skilled users to paddle safely, and so relatively few used them or innovated with respect to them. Finally, in phase 4, the number of users making modifications began to rise again, although they represented only a very small faction of the large overall number of whitewater kayaking participants.

Table 2
Sources of important kayak equipment innovations.

Innovation phase	Innovation source	
	Users	Producers
Phase 1 (1955–1973)	50	0
Phase 2 (1974–2000)	30	10
Phase 3 (1980–1990)	14	0
Phase 4 (2000-today)	0	4
% developed in sector	87%(*n* = 94)	13%(*n* = 14)

5.2. Sources of equipment innovation over time

In Section 4.2 we described the data collection sources and methods used to identify the most important equipment innovations developed in the field of whitewater kayaking over a 50+ year period, and to identify the developers of each of these. Our findings are shown in Table 2.

Note from Table 2 that 87% of the important innovations developed during the history of the sport were developed by users. Note also that the level of activity of user and producer innovators varies greatly over the history of the sport. In Fig. 1, we graphically show the decrease in the frequency of user innovation over time, and also a rise to modest levels of producer innovation over time.

What we see is that, for the first 25 or so years of the sport (phase 1), only users developed innovations judged important by experts. We also see that the rate with which they developed important innovations started out relatively high, then declined over time to zero in phase 4. Producers first became a source of important equipment innovations starting in the mid 1970's. Innovation frequency then rose to modest levels over time and now has begun to decline. User and producer innovators were simultaneously active only in phase 2 of the innovation history of whitewater kayaking.

5.3. Aggregate user expenditures on innovation

In Section 4.3 we described the data collection sources and methods used to determine aggregate levels of user innovation expenditures on whitewater kayaking equipment development over time. Our findings are shown in Table 3.

As can be seen in Table 3, individual users can spend quite significant amounts on innovations related to their hobby of whitewater kayaking. Time expenditures reported by user innovator respondents to our questionnaire were almost two weeks per year on

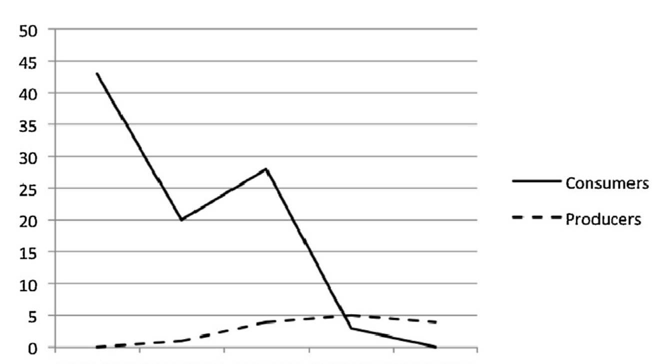

Fig. 1. Whitewater kayaking product innovation sources over time.

Table 3
Annual user product development expenditures.

Innovation phase	Users' whitewater product development Aggregate user spending per year	Users' whitewater product development spending per Individual user spending per year (=1 user's spending/year in time plus money)
Phase 1 (1955–1973)	$5.1 million	$4109
Phase 2 (1974–2000)	$7.5 million	$3752
Phase 3 (1980–1990)	$1.9 million	$3817
Phase 4 (2000–2010)	$6.0 million	$2000
Total over 55 years	$366.7 million	–

Average # innovators per phase × mean annual expenditures for equipment and time invested (with time converted to money equivalent using the minimum wage during that period), adjusted to 2012 dollars (U.S. Department of Labor user price index 2012).

average, and almost a month per year for the most skilled whitewater kayaking innovators. (The latter time expenditure levels are in line with levels found among highly skilled enthusiast practitioners of other extreme sports (Franke and Shah, 2003, Table 3).)

5.4. Aggregate producer expenditures on innovation

In Section 4.4 we described the data collection sources and methods used to determine aggregate levels of producers' direct product development expenditures innovation expenditures on whitewater kayaking equipment development over time. Our findings are shown in Table 4 for all incorporated whitewater kayak producer firms by innovation phase for all phases.

Innovation expenditures adjusted to 2012 dollars (U.S. Department of Labor user price index, 2012)

5.5. Direct cost comparisons of user vs. producer expenditures per innovation

We see in Table 5 that, averaged over the entire history of whitewater kayaking, users are significantly more efficient innovators than producers: they developed important product innovations at 64% of the direct expenditure costs (labor and materials) per innovation incurred by producers. Note that there were doubtless many unsuccessful attempts at innovation by both users and producers. Here, we assign all the costs of both successful and failing efforts to the costs of developing successful innovations.

Within individual phases, it is impossible to compare user and producer development efficiencies except in the case of phase 2: in the other three phases, all of the important innovations in our sample were developed by only one of the two innovator types. Considering phase 2 only, we find that users developed important innovations at 107% of the *direct* project time and materials cost per innovation expended by producers. In other words, given the precision of our data, user and producer direct innovation costs per important innovation in phase 2 are about equal.

5.6. Institutionally-adjusted user and producer innovation cost comparisons

In Table 5, we saw the relative efficiency of user and producer solvers with respect to the amount of *direct* expenditures in labor and materials made by each type of innovator per important innovation developed. This information is useful to compare the direct cost efficiencies of users and producer development employees as solvers.

We now note that these two types of solvers operate within very different institutional contexts. In what follows, we explain and add in two major adjustments arising from the differing contexts of user

Table 4
Direct product development expenditures by business sector firms.

Innovation phase	Average number of firms	Innovation spending/year (in 2012 $)	Phase total (2012 $)
Phase 1 (1955–1973)	4 Minor firms	$563,000 from 4 minor firms	$10.1 million
Phase 2 (1974–2000)	HollowForm (10 years) + Perception + 18 minor firms	$2.37 million ($1.6 million from 18 minor firms, $1.1 million from Hollowform and Perception)	$61.0 million
Phase 3 (1980–1990)	2 Minor firms	$192,000	$1.9 million
Phase 4 (2000–2010)	Jackson Kayaks + 16 minor firms	$1.143 million ($848,000 from 16 minor firms, $ 295,000 from Jackson Kayak)	$11.4 million
Total R&D over 55 years			$84.4 million

Table 5
Direct innovation expenditures per important equipment innovation.

Innovation phase	Producer number of function-improving equipment innovations developed	Producer expenditure per important innovation	User number of function-improving equipment innovations developed	User expenditure per important innovation
Phase 1 (1955–1973)	0	$10.1 million spent–no major innovations	50	$1.8 million
Phase 2 (1974–2000)	10	$6.1 million	30	$6.5 million
Phase 3 (1980–1990)	0	$1.9 million spent–no major innovations	14	$1.4 million
Phase 4 (2000–2010)	4	$3.1 million	0	$60 million spent–no major innovations
Average expenditure per innovation for all phases	14 (13%)	**$6.1 million**	94 (87%)	**$3.9 million**

Table 6
Motivations of kayakers developing equipment innovations.

	User innovators, $N = 201$
Innovation output-related motives	
Expected benefits from personal use	61%
Potential profit from innovation sales	1%
Innovation process-related motives	
Enjoyment from creating the innovation	17%
Learning from creating the innovation	8%
To help others (altruism)	10%
Other motives	2%

and producer innovators. As we will see, both adjustments favor the relative efficiency of user innovation over producer innovation.

The first of the two adjustment factors is the addition of indirect innovation project costs, "overhead," in the case of producer innovators but not user innovators. Producers have indirect costs that they must add to direct project expenditures of labor and materials such as rental of space, and payment of managerial expenses. Our experts in this field inform us that very few or no individual user innovators have similar indirect costs. They tend to work in their homes or garages rather than rent space specifically for pursuit of innovation work related to their hobbies, and they do not pay managers to help organize and control their project activities.

General data on overhead rates for R&D activities are very sparsely reported in the literature. McCullough and Balut (1990, reported in Rogerson, 1992, p. 684) find that for four major aerospace contractors the overhead costs comprise 28% of in-plant costs. Similarly, for the pharmaceutical industry Paul et al. (2010) estimate that overhead costs make up 20–30% of total costs. Thus, a reasonable range for the overhead rates associated with direct costs in that industry would be 25–43%. Additionally, the US National Institutes of Health (NIH) highest "overhead rate" allowed on a Research grant without negotiation is 40% (http://grants.nih.gov/grants/funding/sbir_faqs.htm#510). Based on this data, plus the recollection of kayaking firm manager interviewees regarding their own firms' expenditure patterns, we add 25% to producers' direct costs as an approximate adjustment for overhead.

The second adjustment factor is an adjustment in user innovators' costs according to their *motives* for innovating (Raasch and von Hippel, 2013). In labor economics it has long been argued that firms can pay a lower wage as compensation for work that employees find more desirable in other ways (Smith, 1776, p. 111; Stern, 2004). For this reason, if kayak producer firm employees enjoy working on the innovation tasks to which they are assigned, they will accept a lower wage. These wages are automatically reflected in the actual levels of producer innovation expenditures provided in Table 5.

It seems reasonable that similar considerations would apply to the innovation expenditures of users. To the extent that users value engaging in innovation process activities for their own sake, the portion of their expenditures assigned to generating the innovation *output* should be reduced accordingly. Rewards like "fun gained from development work" in effect are forms of consumption that are associated with participation in the innovation process rather than with the actual output of the process – an innovation – and so can reduce the costs of the inputs actually invested to create the innovation output itself (Raasch and von Hippel, 2013).

To provide quantitative data on this matter, in our questionnaire we asked kayaking user-innovators to describe the relative importance to them of five possible motives for innovating by distributing 100 points across the five motives. The results are shown in Table 6.

The two motives that have to do with profiting from creating the innovation itself (personal use and potential profit), represent about 62% of user innovators' total motivation on average. Three motives related to the innovation process rather than the innovation output (enjoyment of and learning from participating in the innovation process itself, and helping others) account for about 35%; 2% are 'other motives' that we cannot assign to either category. We conclude that 35% of user expenditures on average are actually applicable to 'consumption' of the innovation process rather than development of the innovative output being developed. For this reason, it is appropriate to reduce users time and money expenditures devoted to creating innovation output downward by 35%.

In Table 7, we show user and producer innovation costs adjusted to incorporate both important contextual factors just described. Producer innovation development (R&D) costs have been increased by a conservative 25% to incorporate indirect costs such as management of development and rental of physical space for development work. Also, user innovation costs have been reduced by 35% to include only innovators' expenditures justified by the creation of the innovation, and excluding expenditures justified by innovation process benefits, such as fun and learning.

From Table 7, we see that, with these two institutional adjustments added in, user overall efficiency per important innovation developed is quite considerably higher than producer efficiency in the field of whitewater kayaking equipment development. Across all 4 innovation phases, producers spent in aggregate about 3X more than did users in aggregate per innovation created. In phase 2 where both types of innovators were active at the same time, producers spent a bit less than twice as much as users per innovation developed.

6. Discussion

In this section, we first discuss what we can convincingly conclude about user vs. producer innovation efficiency in the field of whitewater kayaking. We then discuss likely generalizability of the relatively high user innovation efficiency we found. Finally, we more deeply explore the longitudinal shifts in user vs. producer innovation in the history of that sport.

6.1. Innovation efficiency findings

Our basic finding is that individual users are more efficient innovators in terms of direct innovation expenditures per innovation developed than are producer employees. As we saw in Table 7, if we add in the very reasonable contextual factors of overheads that producers must add to their innovation expenditures, and process benefit consumption that must be subtracted from user innovation expenditures, we found that, over the 50 year history of whitewater kayaking, producers as a group spent about 3× more than users as a group on innovation per 'important' innovation developed. In the single phase where both users and producers simultaneously innovated, producers spent about 2× more than users per important innovation developed.

This single finding is important on its own as an existence proof. We find that it is possible for masses of problem-solvers having low apparent coordination to innovate more efficiently than many fewer producer employees when both are addressing the same innovation field. It is the first such finding of which we are aware. Other research into the efficacy of crowdsourcing (e.g., Jeppesen and Lakhani, 2010) concentrates on the ability of members of diverse crowds to quickly solve problems that producer problem-solvers found intractable. That kind of study does not, however, explore the resources expended by the crowd in aggregate to provide a successful solution relative to aggregate expenditures of producer-based solvers to get a similarly successful outcome.

At the same time, our finding sheds no light on the *cause* of the relatively high single user and user community innovation efficiency in the field of whitewater kayaking. In Sections 2.3 and 2.4

Table 7
Context-adjusted expenditures per important equipment innovation.

Innovation phase	Producer number of function-improving equipment innovations developed	Producer expenditure per important innovation (increased by 25% to include overhead)	User number of function-improving equipment innovations developed	User expenditure per important innovation (reduced by 35% to include expenditure on innovation output only)
Phase 1 (1955–1973)	0	$12.7 million spent–no major innovations	50	$1.0 million
Phase 2 (1974–2000)	10	$7.6 million	30	$4.2 million
Phase 3 (1980–1990)	0	$2.4 million spent–no major innovations	14	$0.9 million
Phase 4 (2000–2010)	4	$3.7 million	0	$41.1 million spent–no major innovations
Average expenditure per innovation for all phases	14 (13%)	**$7.6 million**	94 (87%)	**$2.4 million**

we discussed efficiencies of scope as a possible underlying cause, but we do not have the information required to test that hypothesis in the present study. Further research will be required to explore underlying causes and to test hypotheses on the conditions and problem types for which problem-solving by diverse communities can offer an important advantage.

6.2. Potential sources of bias in the analyses

Before accepting the empirical findings we have reported, we must think about possible sources of bias that could affect our analyses. In this regard it is important to ask first: are users and producers devoting the same fraction of their product development budget to the development of "important" innovations? Only if so, can a legitimate efficiency comparison be made. Recall that in our efficiency calculations, we divided the *entire* development budgets of users and producers by the number of important innovations each type of innovator developed. By doing so we included the cost of all failed efforts in the cost of the successful efforts – which seems to us to be entirely reasonable. In addition, however, we implicitly assumed that the same fraction of the development budgets of both users and producers were devoted to the development of 'important' innovations. Is this assumption correct?

It does seem reasonable that users are likely to devote a smaller fraction of their product development budget to innovations that are useful to many, because user innovators are motivated by their own individual need. In contrast, a producer's profits increase along with the scale of the market (generality of need) for an innovation – and so will tend to focus his budget on generally needed innovations that are more likely to be recognized as "important" innovations. This consideration would be conservative with respect to our finding of high efficiency of user development of important innovations.

However, it is also true that producers are certainly aware of user innovation activities, and may adjust the proportion of their product development budget they invest in developing important innovations accordingly. That is, when users are developing many important innovations, producers might find it cheaper to devote their product development budgets to adopting and commercializing user innovations rather than developing their own from scratch. The effect would be to make producers look less efficient with respect to important innovations when user innovation levels are high. In our case, this potential source of bias does not seem to be operating–at least in phase 2. Discussions with two major designers for the most important boat producers in phase 2 and beyond, Coran Addison and Eric Jackson, reveal that in phase 2, the phase where both users and producers were developing a number of important innovations simultaneously, kayak producers were in fact fiercely competitive and devoting major budgetary effort to developing important innovations. Their goal was to develop the best boats in order to win key events in the sport. Related reputational gains would then drive sales.

Recall that our assessments of innovation expenditures by innovating whitewater kayakers are based upon responses to an online survey. It is reasonable that the innovators who responded to our outreach and answered our survey were more engaged in the sport than the average innovator. They were either visiting enthusiast on-line community sites where the survey was publicized or were, in the case of innovators in the earliest phases of the sport, known to leaders in the field as innovators. Those who are more engaged in the sport might have spent more time and money innovating than the average innovating whitewater kayaker. This possible selection bias would skew our findings in a conservative direction with respect user innovation efficiency. It would tend to overstate the level of innovation expenditure in the user community, and so overstate the amount spent by users per important innovation developed by users.

Finally, consider a source of bias that affects our efficiency comparisons across all four phases of the sport taken together, but not our efficiency comparisons with respect to phase 2 only. This bias is introduced because on average user innovations are developed earlier in the history of the field than are producer innovations. The average user innovation therefore presumably costs less than the average producer innovation to develop with respect to the opportunity search component of the innovation process – because the search space is more "mined out" when important producer innovations are developed later in the history of the field (Baldwin et al., 2006). (See discussion in Section 6.3 for more on this.)

We conclude that all but the last source of potential bias in our data either are not operating or are *conservative* with respect to our fundamental finding that user innovators in aggregate are more efficient innovators than producer firms in this field.

6.3. Longitudinal innovation patterns

Recall that in Fig. 1, we saw a striking shift of the rate and locus of innovation and the efficiency of innovation from users to producers as the whitewater kayaking field matured. The general pattern is that important user innovations began at a high level in phase 1, and dropped to zero in phase 4. In contrast, important innovations developed by producers first began in the mid 1970's and rose slowly since then. This pattern has been explained in Baldwin et al. (2006). In essence, the explanation is that, at the start of a new field like whitewater kayaking, all the new things one can do are open for exploration. Further, many of the innovations needed to do them are low-hanging fruit–relatively quick and easy for early users to accomplish. So the rate of user innovation is high. At the same time, from the producer' perspective, the extent of interest in the field as a whole, and specific innovations in particular are not yet known. The market is small and the nature of demand is uncertain and fast-changing – all unattractive features for a producer seeking profits through sales. As the field matures, these factors reverse. The field becomes better explored and easy innovation opportunities have been "mined out" – leading to a drop in the rate of user innovation. At the same time, the commercial demand for products has increased. In net, the market has become larger, the nature of demand more certain, and the rate of change has slowed. All of these features are attractive to producer innovation with respect to certainty of returns from innovative investments. In conjunction with a mining out of innovation opportunities, the effect is the emergence of a lower level of producer innovation. This is precisely the pattern seen in Fig. 1 with respect to both the source and frequency of innovation.

Of course, further theoretical and empirical research may yield more and very different patterns of innovation over time. Interestingly with respect to potential generalizability, however, the only other empirical study of user and producer innovation over time of which we are aware shows exactly the same innovation pattern. Riggs and von Hippel (1994) conducted a quantitative study of innovation patterns in two specialized types of scientific instrument used in surface chemistry studies, Esca and Auger. They found that user innovators entered first developing the first instruments of each type and many follow-on improvements. Next, as the market potential became clear producers entered and began to innovate as well. Finally, first user and then producer innovations declined as the solution space was mined out (Riggs and von Hippel, 1994).

7. Conclusion

We close by again noting that user innovation by individual users is a very important phenomenon – practiced by tens of millions of individual users around the world. The study of efficiency that we have reported upon here is only a first point in a efficiency landscape that is likely to be complex. On its own, the finding that an open, uncoordinated group of users can be as or more efficient than the specialized producer innovators is an interesting surprise with respect to traditional economic and managerial views regarding the sources of efficiency. However, it seems to be potentially explicable in terms of efficiencies of scope.

We suggest that further research will be very useful to understand not only relative efficiencies of collaborative user vs. producer innovation, but to understand the components and drivers of the efficiencies observed. These matters are important for theory, for policy, and for managerial practice.

Acknowledgements

We are very grateful to Sue Taft and Kent Ford, whitewater kayaking historians, and to Eric Jackson and Corran Addison, founders of important and innovative whitewater kayaking firms. All gave us extensive and very generous help in documenting the innovation history of whitewater kayaking. We are also very grateful to Dr. Christina Raasch, MIT Visiting Scholar, and to Professor Scott Stern, for their very helpful suggestions.

Appendix A. Kayaking equipment innovations developed by users

Phase 4 user equipment innovations:
No major equipment innovations from users in phase 4.

Appendix B. Kayaking equipment innovations developed by producers

Phase 1 important producer equipment innovations:
No important producer equipment innovations in Phase 1
Phase 3 important producer equipment innovations:
No important producer innovations in Phase 3

Phase 1 (1955–1973) important user equipment innovations:.

Development of a coaming around the cockpit to prevent water from entering the kayak and to attach different kinds of covers (AWWA, 1956, 1, 19)
Two seater hull design in fiberglass (AWWA, 1956, 14–18)
Knife-like hull design, long and narrow, with bow and stern in the water (AWWA, 1956, 14–18)
Pie-plate hull design, round bottom shape (AWWA, 1956, 14–18)
Development of “rocker” in the hull profile: bow and stern are lifted up, over the water surface, to allow for increase maneuverability of the kayak (AWWA, 1956, 14–18)
Reduced length hull design – shorter than 17 feet – (AWWA, 1956, 14–18)
Flat bottom hull designs (AWWA, 1957, 1, 6–9)
V-bottom hull designs (AWWA, 1957, 1, 6–9)
U-bottom hull designs (AWWA, 1957, 1, 6–9)
Combination of flat, V-bottom and U-bottom hull designs (AWWA, 1957, 1, 6–9)
Fish-form hull designs (the hull seen from the top, looking like the form of a fish) (AWWA, 1957, 1, 6–9)
Anti-fish-form hull designs (AWWA, 1957, 1, 6–9)
Colorado hull designs (having characteristics to fit the heavy whitewater of western rivers, e.g. smaller and more volume) (AWWA, 1957, 3, 17)
European racing hull designs (rather long, thin and sharp hull designs for speed and slalom techniques) (AWWA, 1957, 3, 17)
Rogue hull designs (a transition design having both recreational purpose but also some elements of sharp edges and V-design for fast paddling and slalom techniques) (AWWA, 1957, 3, 17)
Ultra light kayak (30 pounds) with integrated sprayskirt (AWWA, 1961, 3, 34)
Fiberglas surfing bow plate (AWWA, 1971, 2, 57)
The “shoe” – a surf kayak (AWWA, 1971, 2, 58)
Knee pads inside the kayak hull to take away pressure from the knees (AWWA, 1956, 1, 18)
Elastic sprayskirt cover, where a rope is used to fix the cover underneath the coaming (AWWA, 1956, 1, 19)
Sprayskirt where the paddler sits in a long tube to keep the boat dry (AWWA, 1956, 1, 19)
Development of a sprayskirt cover that can be opened and closed using zippers and clips (open for flat water, closed for whitewater) (AWWA, 1956, 1, 20)
Development of a ripper for the sprayskirt to be able to slip out of the kayak in case of emergency (AWWA, 1956, 1, 20)
Extending commercially available gloves by means of canvas to the elbow and then dipping them in latex (to keep hands dry and warm) (AWWA, 1956, 1, 20)
Putting fiberglass resins around wooden paddle shafts to make them stronger (AWWA, 1956, 1, 20)
“Rouge river” spray cover: two plywood parts with attached cover that can be used to close an open kayak for paddling in cold or white water (AWWA, 1956, 3, 8–9)
Metal tip guards for paddle blades–to protect the paddle blade from breaking (AWWA, 1956, 3, 23)
Using fiberglass as paddle tip guards instead of metal. Lighter and more rugged solution. (AWWA, 1956, 3, 23)
Rudder for kayak (AWWA, 1956, 4, 23)
Floatation to prevent tipovers of kayaks (AWWA, 1957, 1, 21)
Flat paddle blade (AWWA 1959, 3, 14)
Curved paddle blade (AWWA 1959, 3, 14)
90° feathered paddle shaft (AWWA 1959, 3, 14)
Wet suit for kayaking (AWWA, 1960, 1, 16–17)
Dry suit for kayaking (AWWA, 1960, 1, 16–17)
Floatation and storage bags (AWWA, 1960, 1, 30–34)
Foam rubber boots worn by skin divers–used in kayaking (AWWA, 1960, 2, 48)
Neoprene sleeve (for warmer hands in cold water) (AWWA, 1970, 1, 12)
Wetsuit-material sprayskirt and release for that sprayskirt (AWWA, 1970, 2, 15–18)
Feather kayak paddle (developed by the Feather river kayak club) – a paddle that has a flat blade but slight angle toward the shaft and therefore has increased pressure similar to a “spooned” blade (AWWA, 1971, 3, 86–89)
Eskimo roll trainer (AWWA, 1957, 2, 16)
Crash helmet for class IV and V river (AWWA, 1957, 2, 23)
Snorkel on the spraycover for breathing air when turned upside down (AWWA, 1962, 3, 16)
Breathing device/snorkel used inside the tunnel of the sprayskirt (AWWA, 1963, 1, 24–25)
First forms of lifejackets specifically for whitewater (AWWA, 1963, 2, 27–29)
Using a car wheel inner tube to prevent being flipped over by a wave (mounting it on the top of the bow, AWWA, 2, 57)
Rescue handle (AWWA, 1971, 4, 135)
Safety ropes for rescue (on the kayak deck, AWWA, 1957, 1, 22)
Rope with floatation at the end (AWWA, 1957, 2, 23)

Phase 2 (1974–2000) important user equipment innovations:.

- Using foam as hip pads (AWWA, 1974, 1, 31)
- Neoprene "shorty" (AWWA, 1979, 2, 12–13)
- Specific whitewater helmet with holes for water drainage and low on forehead and temple (AWWA, 1973, 1, 15)
- Heaving line with monkey fist as rescue rope (AWWA, 1973, 2, 52–55)
- Tow line as a "third hand" to rescue boats (AWWA, 1974, 5, 172)
- Sharp bow of the kayak hull (AWWA, 1975, 5, 161)
- Shorter kayak hull design (going below 4 meter length. . ., AWWA, 1976, 2, 56–57)
- Boat rescue rope on the deck of the kayak using safety and quick release mechanisms (AWWA, 1976, 4, 122)
- Stuff bag (rope lined up inside) (AWWA, 1976, 5, 164–165)
- Drain plug holes (Interview with Sue Taft, 2012)
- Reduction of air volume at the kayak ends (Interview with Sue Taft, 2012)
- Increasing the air volume around the paddler (innovation data from Hienerth, 2006, Interview Sue Taft 2012)
- Release louvers (innovation data from Hienerth, 2006, Interview Sue Taft, 2012)
- A short but voluminous kayak for creeking (AWWA, 1990, 4, 31, Topolino, based on a first design by Holger Machatschek, personal interview, 2009, Interview Sue Taft, 2012)
- Kayak hulls in various sizes for different sizes of paddlers (Interview with Pulliam and with Sarborough, 2009, Interview Sue Taft 2012)
- "ducky bow"–a round bow to avoid pinning (AWWA, 1990, 3, 27)
- The Suisse banana (a kayak hull that could be paddled both sides – it was exactly symmetrical; Interview with Machatschek, 2009)
- Spray skirt for whitewater and also for larger keyhole (Taft, 2001, data from Hienerth, 2006)
- Novel (oval/asymmetrical) paddle blade shape (Data from Hienerth, 2006)
- Kevlar-Fiberglass paddle blade with raised center line of the blade (AWWA, 1981, 3, 16)
- Development of a back strap. (Using polymate FRXFR 120 globe belting. It is four inches wide and made of nitro-impregnated polyester with a tensile strength of four hundred pounds). (AWWA, 1985, 2, 31–32)
- Safety foot brace (Interview Machatschek, 2009)
- Larger keyhole (Taft, 2001; data from Hienerth, 2006)
- Grand-Canyon style life-vest (Data from Hienerth, 2006)
- Life-vest with attached rope (Interview Machatschek, 2009)
- Air tank for breathing in the back of the kayak, linked with a rubber valve to the helmet of the kayaker (AWWA, 1980, 3, 9)
- Safety: grab loops not only at the end – more safety loops incorporated into the plastic kayak (Interview with Sue Taft, 2012)
- Protection gear for elbows and back (innovation data from Hienerth, 2006, Interview Sue Taft, 2012)
- Using an extended stick for rescuing the paddler (Interview with Machatschek, 2009)
- Overthruster – (Jerome Truran 1986) Immersion Research (users did it first - people putting beach balls into to keep spray skirts up in the 80's producers did it later)

Phase 3 (1980–1990) important user equipment innovations:.

- Reduction of length (length at around 3 meters and less)
  - Various individualizations (Taft, 2001, 232–239; Interview with Singleton, 2009)
- Reduction of air volume
  - Various individualizations (Taft, 2001, 232–239; Interview with Singleton, 2009)
- Introduction of sharper edges on the side of the kayak to be able so submerge the hull
  - Various individualizations (Taft, 2001, 232–239; Interview with Singleton, 2009)
- Rather flat displacement hull, not yet planning hull
  - Various individualizations (Taft, 2001, 232–239; Interview with Singleton, 2009)
- Custom fit of hull to individual paddler (height, weight)
  - (Interview with Singleton, 2009)
- Foot bumps (very flat kayaks would otherwise not have space for the feet of the kayaker)
  - (Data from Hienerth, 2006)
- Knee bumps (space for the knee in flat kayaks; Interview with Sue Taft 2012)
- Modification of cockpit rim – and sprayskirt tunnel design (Interview with Sue Taft 2012)
- Incorporation of sprayskirt tunnel with kayak vest (Interview with Sue Taft 2012)
- Weight chop (Interview with Sue Taft 2012)
- Wooden paddles with non standard offsets (Taft, 2001, 238)
- Air foil form paddle (AWWA, 1990, 4, 14)
- Paddle vests for being submerged most of the time (Taft, 2001, 236–240)
- Clothing for being submerged most of the time (Taft, 2001, 236–240)

Phase 2 1973–2000 important producer equipment innovations:.

Hardware innovations	Innovating producer
Plastic hull (Data from Hienerth, 2006; Taft, 2001)	Hollowform 1973 (later on Perception introduced rotational molding)
Dry suit with front entry (AWWA, 1986, 2, 20)	Stohlquist
Safety deck system (a part of the deck of the kayak that can be broken away in the case of pinning (AWWA, 1985, 2, 31–35)	Rick Curtis and Tom Kreutz from Outdoor Safety Systems
Reinforcement plate underneath the seat to prevent boats from breaking if they are pinned ("Beene Pod", specifically for plastic boats - AWWA, 1985, 4, 36)	Ken Horwitz for Hydra Boats
Major reduction of length (using plastic for the hull) (innovation data from Hienerth, 2006)	Eskimo Topolino kayak 1980 was the first big move toward length reduction – became a long-term trend
Developing various forms and functions of edges to break adhesion to the wave (innovation data from Hienerth, 2006, interview Sue Taft 2012)	1995 Corran Addison (first working as a designer for Perception, then for Savage Designs, then Riot)
Introducing a flat planning hull for surfing with the kayak (innovation data from Hienerth, 2006)	1995 Corran Addison (first working as a designer for Perception, then, Savage Designs then Riot)
Spin groove (innovation data from Hienerth, 2006)	1997 Riot Kayaks
Golf-ball sized divots (indentations) (innovation data from Hienerth, 2006)	1997 Riot Kayaks
Scoops in bow and stern (innovation data from Hienerth, 2006)	Wave Sport 1986, Perception 1988

Phase 4 2000–2010 important producer equipment innovations:.

Hardware innovations	Innovating producer/employee
Air volume tank (innovation data from Hienerth, 2006)	Wave Sport Kayaks
Adaptable bow and stern (innovation data from Hienerth, 2006)	Eric Jackson Kayaks Transformer 2001 (bolt-on ends you could add on and take off).
Air hip pads (innovation data from Hienerth, 2006)	Jackson Kayaks Pyranha, 2002
Formable footbrace (innov data from Hienerth, 2006)	Jackson Kayaks 2002

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