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## Is necessity the mother of disruption?

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# KIEL WORKING PAPER

**Is Necessity the  
Mother of Disruption?**

A photograph showing a close-up of hands working at a desk. One hand is holding a yellow sticky note, while the other is resting on the desk. There are several other yellow sticky notes scattered around, along with a black marker and a white notebook. The background is slightly blurred, focusing attention on the hands and the desk items.

*No. 2097 December 2017*

*Stephanie Preißner, Christina Raasch, and Tim Schweisfurth*

# ABSTRACT

## IS NECESSITY THE MOTHER OF DISRUPTION?

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This study investigates the origins of disruptive innovation. According to the canonical model, disruptive innovations do not originate from existing customers - in contrast with what the user innovation literature would predict. We compiled a unique historical and content-analytic dataset based on 62 cases identified from the disruptive innovation literature. We found that 44% of the disruptive innovations in this sample were originally developed by users. Disruptive innovations are more likely to originate from users (producers) if the environment is characterized by high levels of turbulence in customer preferences (technology). Disruptive innovations involving high functional (technological) novelty, tend to be developed by users (producers). Users are also more likely to be the source of disruptive process innovations, and to innovate in weaker appropriability environments. Our paper is among the first to link the disruptive and user innovation literatures. We contribute to both and offer guidance to managers on the likely source of disruptive threats.

**Keywords:** user innovation, disruptive innovation, market orientation, radical innovation, environmental turbulence

**JEL classification:** D83, L17, M19, O31, O34

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## 1. Introduction

Predicting disruption before it happens is a challenging task for firms (Govindarajan et al., 2011; Klenner et al., 2013). Incumbents who know where and how to search for potential disruptions, are better equipped to respond to radical change (Roy and Cohen, 2015; Roy and Sarkar, 2015). To make their search more effective and efficient, such firms need to understand which types of sources are likely to produce disruptive innovations, given the conditions of their specific industry. In short, managers and strategists in incumbent firms, responsible for protecting their businesses from disruptive threats, would benefit substantially from answers to the fundamental question where disruptive innovations originate.

However, the current literature disagrees about the origins of disruptive innovation. Disruptive innovation canon has it that new market entrants are the source of disruptive innovations whereas incumbent firms are at a comparative disadvantage due to their focus on their existing customers' preferences (Christensen, 2011; Christensen and Rosenbloom, 1995). Existing customers are regarded as unlikely to be the source of disruptive innovations, as by definition, they initially do not value such innovations.

On the other side of the debate, the user innovation literature, while not studying disruptive innovation as such, offers extensive evidence of users being a frequent source of breakthrough innovation (Baldwin et al., 2006; Lilien et al., 2002; von Hippel, 1988). For instance, von Hippel (1976) finds that 80% of the functionally novel innovations in the area of scientific instruments were developed by users seeking to solve their own use-related problems rather than by producers seeking to profit from selling these innovations. In contrast, Christensen (2011, p.68) "predict[s] that the innovations toward which the customers in von Hippel's study led their suppliers would have been sustaining innovations. We would expect disruptive innovations to have come from other sources."

In the present paper we conduct a quantitative empirical assessment of the origins of disruptive innovation. We investigate the contingencies favoring the different sources of disruptive innovation to build a link between the disruptive innovation and user innovation literatures. We draw on existing disruptive innovation theory, user

innovation theory, industry evolution research, and competence-based explanations to derive hypotheses about the sources of disruptive innovation. Our hypotheses consider the characteristics of both the innovation and its context as predictors of the source of disruptive innovation, that is, whether the innovations are developed by users or producers. To test our hypotheses, we conducted a systematic literature review and compiled a set of 62 historical innovations identified in the disruptive innovation literature. They include well-known cases such as the Internet, 3D printers, and laser eye surgery. For these cases, we built a unique dataset based on extensive secondary data presented as case vignettes, which were coded by five independent raters.

Our findings can be summarized as follows. Forty-four percent of disruptive innovations in our sample originate from users, and the same percentage originate from producers (including incumbents and new entrants). The remaining 12% originate from other sources such as research labs. We find that disruptive innovations are more likely to originate from users if the environment is characterized by a high degree of turbulence in customer preferences. Disruptive innovation is more likely to stem from producers in technologically turbulent environments. Environments with weak appropriability regimes favor disruptive user innovations. We also find that disruptive innovations involving high functional novelty tend to be developed by users, while those involving radical technological changes are more likely to originate from producers. We find weaker evidence that users are more likely than producers to be the source of process and technique innovations, while the reverse applies to product innovations.

By advancing and testing hypotheses on the origins of disruptive innovation, we marry the innovation and disruptive innovation literatures and reconcile some of their contradictions. This study is among the first to connect these influential research streams. We add to the understanding of the early development phases of disruptive innovations, which to date is largely neglected in the literature, and inform the debate about the value of customer or market orientation in the face of disruptive threats. Our study also contributes to the user innovation literature by extending our understanding of the conditions favoring the two sources of innovation. We offer new explanations for inter-industry differences in the prevalence of user innovation and also

contribute to nascent research on technique innovations by users as well as participators as a third source of innovation (von Hippel, 2017).

Our results can inform managerial practice by offering a contingent explanation of the most likely source of path-breaking innovations. There is extensive research explaining why large incumbents may fail to recognize the potential of such innovations and then find themselves threatened by new entrants (Christensen, 2011; Christensen and Rosenbloom, 1995; Christensen et al., 2015). This knowledge needs to be supported by a theory explaining the sources of disruptive innovation for incumbents to be better able to identify potentially disruptive threats early on.

The remainder of the paper is structured as follows: section 2 explains the theoretical background to our study and the research gap it addresses. Section 3 develops the research model and section 4 describes the empirical methodology. Section 5, the main part of the paper, presents the empirical results. Section 6 discusses our findings and implications for research and practice.

## **2. Theory**

### *2.1 Disruptive innovation*

There is a rich literature on discontinuous shifts in the technological evolution of industries (Christensen and Rosenbloom, 1995; Henderson and Clark, 1990; Nelson and Winter, 1977; Tripsas, 2008; Tushman and Anderson, 1986). Traditionally, a distinction is drawn between supply-side theories which are focused on interactions between technological conditions and characteristics of the supplying firms, and demand-side theories which are focused on the impact of consumer needs on technological development. In the latter group, the research on disruptive innovation by Christensen and his co-authors has been the most influential (Adner, 2002).

Disruptive innovations are innovations that introduce a different value proposition from the existing market offerings but are inferior along the performance dimensions most valued by mainstream customers. Thus,

disruptive innovation is not defined by technological breakthrough. Rather, it is defined by, and can be identified in customers' perceptions of performance (Christensen and Bower, 1995, 1996; Crockett et al., 2013; Yu and Hang, 2010). Initially, disruptive innovations satisfy niche customers who appreciate the non-standard performance package (Adner, 2002; Christensen, 2011). Actual disruption occurs when “further development raises the disruptive technology’s performance on the focal mainstream attributes to a level sufficient to satisfy mainstream customers” (Adner, 2002, p.668).

Disruptive innovations pose a threat to and can even cause the demise of incumbent firms (Christensen, 2011; Christensen and Bower, 1995; King and Baatartogtokh, 2015). According to disruptive innovation theory, incumbent firms tend to disregard such innovations since they do not meet existing customers’ requirements. Incumbent firms' resource allocation processes (Christensen and Bower, 1996), organizational capabilities (Bergek et al., 2013; Charitou and Markides, 2003; Henderson, 2006), and power structures (Henderson, 2006) are geared to meeting current customer needs. Organizational competencies related to markets and customers are developed through the long-term development of routines, cognitive models, and shared systems of understanding (Henderson, 2006). Such competencies do not equip incumbents to react to latent and emerging customer needs (Beverland et al., 2010). In addition, Christensen and Rosenbloom (1995) emphasize that incumbent firms’ value networks and particularly supplier networks are oriented towards the existing product offering. For all these reasons, incumbents tend to allocate resources to sustaining innovations targeting mainstream customers, and to discount the potential of disruptive innovations that develop in market niches (Christensen, 2011).

To guard against disruptive innovation, this stream of literature advises incumbent firms to be on the lookout for new entrants from unrelated industries since for them, disruptive innovation does not cannibalize existing product offerings (Christensen and Rosenbloom, 1995). Following Klenner et al. (2013), incumbent firms should monitor the disruptive susceptibility of their value network, i.e., “the readiness level of a market for a potential disruptive innovation and the time frame in which the potential disruptive innovation will enter the market”

(Klenner et al., 2013, p. 916). Most importantly in the context of the present paper, earlier literature on disruption indicates that it is not worthwhile and could be dangerous for incumbents to look for disruptive ideas and innovations among current customers (Christensen, 2011; Christensen and Bower, 1996): “Our conclusion is that a primary reason why such firms lose their positions of industry leadership when faced with certain types of technological change has little to do with technology itself. [...] Rather, they fail because they listen too carefully to their customers – and customers place stringent limits on the strategies firms can and cannot pursue” (Christensen and Bower, 1996, p. 198).

Subsequent studies have toned down this customer-skeptical view. Christensen (2006, p.51) refines this position as follows: “A more accurate prescriptive statement is that managers always must listen to customers. They simply must be aware of the direction in which different customers will lead them. A customer will rarely lead its supplier to develop products that the customer cannot use. The right lead customers for sustaining innovations are different from those for disruptive innovations. And *the lead users for new-market innovations may not yet be users [of the firm’s current product offerings].*” (italics added by the authors) Supporting this perspective, firms have been found to fare better in the face of disruption if they attend to emerging customer groups. Emerging customers are “not the current focal point of business, but they have the potential to become more important” (Govindarajan et al., 2011, p.122). Whereas attending to current customers is negatively related to the creation of disruptive innovation, focusing on emergent customers is positively related the creation of disruptive innovation (Govindarajan et al., 2011). This does also pertain to users of the disruptive technology who are located inside the boundaries of the organization. Incumbents with access to such in-house users have been found to do better when being faced with disruptive change (Roy and Cohen, 2015).

Summarizing disruptive innovation canon, such innovations are most likely to emerge with new market entrants from unrelated markets (Christensen and Rosenbloom, 1995). It should be noted, however, that this literature mostly focuses on the commercialization phase – Christensen and co-authors argue that disruptive innovations are likely to be *commercialized* by new market entrants (Christensen, 2011; Christensen and Rosenbloom, 1995)

– but pays scant attention to the earlier phases of the innovation process. In this paper, we zoom in on these early phases of the innovation process and examine the locus of first invention, prototype, and early development of disruptive innovations.

## 2.2 *User innovation*

Innovators – individuals and firms – can be categorized according to their relationship with their innovation, that is the type of benefit the innovator expects from innovating (von Hippel, 1988). Researchers and policymakers have long assumed that the incentive to innovate is the expectation of economic profit. In this view, the principal source of innovation is the *producer innovator*. Producer innovators are defined by the profit motive which drives them to innovate (von Hippel, 1982). Examples of producer innovators are individuals or firms that patent an innovation in order to license it to others, firms that design a new process machine to sell to their customers, and firms that devise a new service offer for their clients (von Hippel, 2005).

Users have been identified as another source of innovation (Baldwin and von Hippel, 2011; von Hippel, 1976; von Hippel et al., 2011). *User innovators* are defined as firms or individuals whose principal motivation to develop a new product or service is their own need for it. Examples of user innovators are firms designing process machines for their own use, a surgeon who develops a new medical device to facilitate surgical operations, and an individual consumer who writes a new software program to organize his/her own files (Dahlander and McKelvey, 2005; Lettl et al., 2006b; Urban and von Hippel, 1988). Representative national studies show that in the U.S., the U.K., and other countries some 5% of the consumer population are user innovators who develop and modify products for their own use (de Jong et al., 2015; von Hippel et al., 2012; von Hippel et al., 2011). There are also large-scale, cross-industry studies providing evidence of the ubiquity of user innovation by firms with regard to their internal processes, machinery, and equipment (Flowers et al., 2010; Schaan and Uhrbach, 2008).

Interestingly, producer innovation has been shown to dominate in particular product domains such as tractor shovels, engineering thermoplastics, and plastics additives (von Hippel, 1988), while user innovation prevails in areas such as semiconductors (von Hippel, 1977), medical devices (Shaw, 1985), and scientific instruments (von Hippel, 1976). A number of factors have been suggested to explain this variance:

First, innovators differ in terms of their knowledge sets and this affects their innovation behavior. When developing new products or processes, innovators tend to rely on local, easily accessible knowledge (Lüthje et al., 2005; Riggs and von Hippel, 1994; von Hippel, 1994b). Users have situated need knowledge, gathered through personal use experience (von Hippel, 1994b). In contrast, the strength of producer innovators typically lies in technological solution knowledge embedded in R&D functions and processes (Chatterji and Fabrizio, 2013; Hienerth et al., 2014; Ogawa, 1998). External knowledge acquisition is usually costly because innovation-related knowledge tends to be tacit and sticky, and thus difficult to transfer. Sticky need-related information favors innovation by users (Lüthje et al., 2005; von Hippel, 1994b).

Second, it has been argued that appropriability of the benefits from an innovation is predictive of its source. Actors will allocate resources to innovation activity if the benefits they expect to appropriate from the innovation exceed their innovation costs (Riggs and von Hippel, 1994; von Hippel, 1982, 1988). Related factors which have been advanced to explain the source of innovation include differences in cost structures (Franke and Shah, 2003; Lüthje, 2004), agency issues between users and producers (von Hippel, 2005), and regulatory impediments (Braun and Herstatt, 2007; Torrance and von Hippel, 2013).

The user innovation literature provides extensive evidence that users are often the source of innovations involving high levels of novelty (Lettl et al., 2006b; Lilien et al., 2002; Poetz and Schreier, 2012). It highlights lead users (i.e., users who experience needs ahead of others and stand to benefit greatly from a solution addressing their need) as an important source of radical innovations which meet new customer needs (Riggs and von Hippel, 1994; von Hippel, 1976, 1977).

To date, however, the user innovation literature has not studied disruptive innovation as such. In their review, Bogers et al. (2010) stress the need for a link between the user innovation literature and other research streams to leverage its findings to extend our understanding of radical, architectural, and disruptive innovation.

### *2.3 Research gap and objectives*

To our knowledge, the different perspectives in the user innovation and disruptive innovation literatures have never been linked and compared. To date, there are no studies that investigate the sources of disruptive innovations, or extend user innovation theory to explain phenomena related specifically to discontinuous shifts in industry evolution.

At first glance, the literatures on user innovation and disruptive innovation appear *complementary*: the former addresses the origins of innovation, while the latter focuses mostly on its subsequent commercialization and consequences for firm success – specifically on the firms most likely to introduce disruptive innovations on the market and the effects on incumbent producers. Although it discusses the key role of new market entrants in the *commercialization* of disruptive innovations, this literature is virtually silent about the locus of their *invention* and subsequent development.

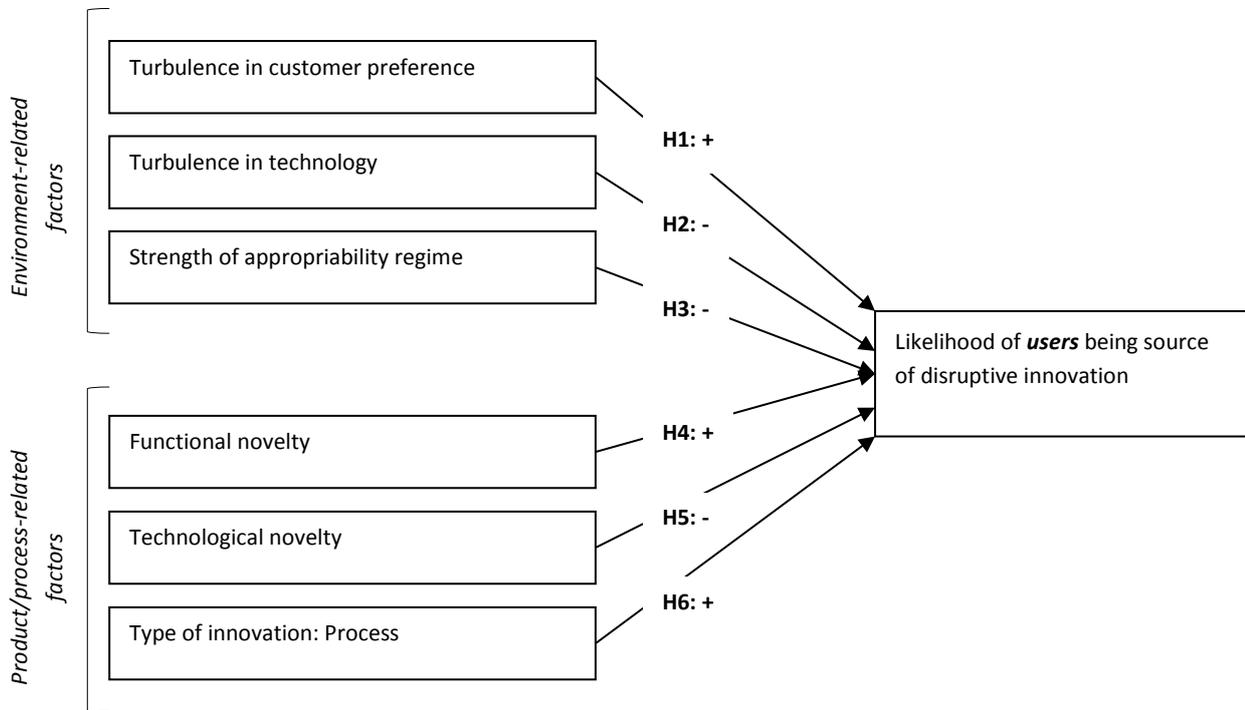
However, to some extent, these two literature strands make mutually contradictory claims. The literature on user innovation emphasizes that producer firms typically benefit from information spillovers from user innovators and can increase their innovation performance by involving current users in the innovation process (Chatterji and Fabrizio, 2012; Franke et al., 2006; Gambardella et al., Forthcoming; Shah and Tripsas, 2007). In contrast, the literature on disruptive innovation predicts that incumbents that allow themselves to be guided by existing customers risk overlooking emergent market needs and falling behind in terms of innovation (Christensen, 2011; Christensen and Bower, 1996). According to Christensen, user innovations such as those studied by von Hippel and his co-authors are likely to be sustaining, that is non-disruptive innovations (cf. the quote in the introduction section).

In our view, these considerations highlight the need for a better understanding of whether, and if so under what conditions, disruptive innovation is likely to originate from (lead) users, including current customers. An empirical investigation into the origins of disruptive innovation seems warranted to exploit the complementarity between the two strands of literature and to disentangle the unresolved contradictions.

### **3. Research model**

In this section, we formulate contingent hypotheses about the sources of disruptive innovation. Our arguments build on the disruptive innovation and user innovation literatures. We take a competence-based perspective on disruptive innovation (Henderson, 2006), focusing on technological and customer competencies (Danneels, 2002; Govindarajan et al., 2011; Roy and Sarkar, 2015). Our argumentation is based on the assumption that users, *ceteris paribus*, have especially strong customer competence whereas producers have stronger technological competence. As both types of competences are crucial for disruptive innovation, we expect to find both users and producers as sources of disruptive innovations. After all, research has suggested that an actors' competencies affect how (1) actors recognize disruptive shifts in the environment and (2) how they respond to them (Danneels, 2004; Henderson, 2006). In this paper, we follow this view and argue that, due to their unequal competences, users and producers differ in how (1) they interpret the environment and (2) how they innovate. Thus, we investigate how (1) environment-related factors (sections 3.1 and 3.2) and (2) product/process-related factors (sections 3.3 and 3.4) explain the likelihood of users or producers being the source of disruptive innovation (i.e. the actor that built the first functional prototype of a disruptive innovation). Figure 1 summarizes our research model.

Figure 1: Research model



### 3.1 Contextual characteristics: Turbulence

A key attribute often used to describe the conditions in a given industry is industry turbulence, that is, the dynamism of the market environment (Calantone et al., 2003; Volberda, 1996; Volberda et al., 2012). Turbulent environments have been shown to pose particular challenges, for example with regard to top management decision making (Bourgeois Iii, 1985; Eisenhardt, 1989), firm capabilities (Song et al., 2005), and new product development (Bhattacharya and Krishnan, 1998; Calantone et al., 2003). Turbulence creates uncertainty for innovators, (O'Connor, 1998; O'Connor and Veryzer, 2001) and requires higher levels of responsiveness (Volberda et al., 2012). At the same time, turbulent environments also provide opportunities for those organizations that pick up, interpret, and use external cues for innovation (Cohen and Levinthal, 1990a).

Contextual turbulence has various sub-dimensions which distinguish the sources of the change (Volberda et al., 2012), the most important being turbulence in customer preferences, and technological turbulence (Dröge et al., 2008; Miller and Dröge, 1986).

### *3.1.1 Turbulence in customer preferences*

Preference trajectories are generally characterized by periods of incremental evolution, punctuated by discontinuous changes (Tripsas, 2008). Discontinuous changes, that is major shifts in customer preferences, have been shown to foster technological transition by altering the relative attractiveness of technological alternatives. Higher turbulence in customer preferences is thus related to higher susceptibility of a market to being disrupted (Klenner et al., 2013). (By “market” we mean “a set of consumers whose similar needs are being served by a set of competing technologies, firms, and brands” (Sood and Tellis, 2011, p. 340). Thus, even if an emerging customer segment should value secondary dimensions of competition differently than existing customers, both are still part of the same market. Disk drives are a case in point: even if emerging customers preferred different architectures than existing customers, they still shared the overarching need for storage capacity (Sood and Tellis, 2011.) Turbulences in market needs arise when secondary dimensions become newly important or performance requirements for primary dimensions change (Tripsas, 2008).

Actor-specific competences influence the likelihood of dealing successfully with such shifts (Bergek et al., 2013; Henderson, 2006). We argue that users and producers differ in their competences under varying levels of preference discontinuity. We expect users rather than producers to be the source of disruptive innovation in a context characterized by high turbulence in preferences. They are better able to recognize shifts in preferences early on because they have situated need knowledge deriving from their own use experience and via social ties with other users, (Franke and Shah, 2003; Hienerth and Lettl, 2011; Morrison et al., 2000).

First, users utilize products and processes in a natural context. Thus, they are more likely to become aware of the deficiencies of existing solutions, and changing requirements in the user domain. Users tend to rely on

this local knowledge when innovating (Lüthje et al., 2005). Prior empirical research confirms that users are often the first to identify unmet needs in a given market (Lilien et al., 2002; von Hippel et al., 1999) and to innovate for themselves. Lead users, in particular, experience needs long before the general market, and stand to benefit significantly from finding a solution to these needs, which makes them a likely source of innovation (Franke et al., 2006; von Hippel, 1986).

Second, users are embedded in user networks (von Hippel, 2007). In these networks they exchange ideas, share information about their needs, and discuss use-related trends. This access to other users gives them an informational advantage in sensing customer preference discontinuities early on. While, in principle, producers can also forge social ties to users, they are less likely than users to profit from it as they lack the absorptive capacity to accurately interpret information embedded in user ties (Cohen and Levinthal, 1990a; von Hippel, 1994a). E.g., qualitative empirical research in the typesetting industry found that users were the first to recognize and commercially exploit new opportunities opened up by preference discontinuities because of “their unique understanding of needs” (Tripsas, 2008).

In some cases, firms have users inside their own boundaries, either as corporate units (Roy and Sarkar, 2015) or as individual users (Schweisfurth and Raasch, 2015). These firms are better positioned to handle potential disruption as in-house users “can help exploration efforts with new information about demand conditions and the product performance features that customers are likely to value” (Roy and Sarkar, 2015, p. 839). Even if producers can augment their customer competence by incorporating users, we argue that not all firms necessarily do so. In general, we would expect users to be equipped to pick up and interpret changes in customer preferences earlier and more accurately than producers.

These arguments lead to the following hypothesis:

*H1: In environments characterized by high turbulence in customer preferences, disruptive innovations tend to originate from users rather than producers.*

### *3.1.2 Turbulence in technology*

Technological turbulence refers to discontinuity caused by technological innovations (Calantone et al., 2003). Industry evolution is characterized by periods of incremental technological change punctuated by discontinuous shifts, which can change the industry structure significantly (Anderson and Tushman, 1990; Tushman and Anderson, 1986). We expect producers rather than users to be the source of disruptive innovation if the environment is characterized by high technological turbulence. The principal reason is that producers can understand and interpret changes in technology better and more accurately than users due to their technological competence.

Turbulence in technology introduces changes and variations in technology for all potential innovators. The actors, both users and producers, need to process these changes, i.e. they need to recognize and make sense of technological variation (Tripsas, 2008). Due to their specific competences, we expect producers to be better able to profit from technological turbulence and variation. Compared to users, producers possess more extensive solution knowledge, and complementary assets (Chatterji and Fabrizio, 2012; von Hippel, 1988), as well as second-order technological competence to understand additional solution knowledge (Danneels, 2002). This increases their absorptive capacity for new technologies (Cohen and Levinthal, 1990b), and positions them better to learn about new technology-related opportunities emerging in their industry environment.

For users, technological change is more difficult to notice and accommodate. Compared to producers, their technological competences are likely to be less pronounced. This renders them less likely to recognize and correctly make sense of opportunities rooted in environmental technological change (Cohen and Levinthal, 1990a).

For these reasons, we hypothesize that:

*H2: In environments characterized by high technological turbulence, disruptive innovations tend to originate from producers rather than users.*

### *3.2 Contextual characteristics: Appropriability regime*

The term appropriability regime refers to the characteristics of the environment that influence innovators' ability to capture returns from innovation. Its strength is determined by the nature of the technology, specifically its complexity and imitability, and the efficacy of the intellectual property (IP) regime (Teece, 1986).

We expect the sources of disruptive innovation to depend on the extent to which innovators in a given environment can appropriate economic returns from innovation. Strong appropriability provides the incentives that producer innovators require, by reducing imitation competition and facilitating value capture in the form of economic profit from selling the innovation (Arrow, 1962). In such environments, producers can draw on existing competences for value appropriation (Reitzig and Puranam, 2009). Conversely, since producer innovators innovate in order to sell their innovation for profit (von Hippel, 1988), weak appropriability regimes that facilitate value slippage to other economic actors are less likely to stimulate producer innovation. In such environments, users are still capable to appropriate value from inventions, as they expect immediate rewards from their innovation through their own usage (Baldwin and von Hippel, 2011). In fact, most user innovators do not seek IP protection for their innovations at all (de Jong et al., 2015; von Hippel et al., 2012). Also, it has been shown that weak appropriability can *support* user innovation by encouraging free diffusion of innovation-related information (Baldwin and Clark, 2006; Harhoff et al., 2003), for example in user innovation communities (Meyer, 2003). By freely revealing their innovative designs and ideas, users obtain benefits in the form of feedback and development assistance, reputational gains, and potentially preferential access to a commercial producer offering based on their ideas (de Jong and von Hippel, 2009; Henkel, 2006; von Hippel and von Krogh, 2003). Finally, users requiring a disruptive new product may be less inclined to wait for producer innovation to address their need given that producers are less likely to launch an offer in weak appropriability conditions. Based on these arguments, we propose that:

*H3: In environments characterized by weak appropriability regimes, disruptive innovations tend to originate from users.*

### 3.3 Innovation characteristics: Novelty

#### 3.3.1 Degree of functional novelty

Functional novelty describes the degree to which the functions or applications provided by a product or process are new to the market, thereby addressing hitherto unmet user needs (Garcia and Calantone, 2002). Even if *some* new functional performance features are an integral part of disruptive innovation (Govindarajan and Kopalle, 2006b), the *degree* of functional novelty provided by these features may vary significantly (Christensen and Raynor, 2010). Examples of disruptive innovations with a high degree of functional novelty are the photocopier and transistor pocket radio, which created entirely new markets (Christensen and Raynor, 2010). An example for a disruptive innovation with a low degree of functional novelty is grid computing which essentially offered the same functionality as the incumbent technology of massively parallel processing while relying on a simpler, decentralized computing technology (Jakob et al., 2005). Another example are steel minimills, which provided a similar functionality as integrated mills (produce steel), but at a lower cost (Christensen and Raynor, 2010).

We expect that disruptive innovation from users are more likely to incorporate a higher degree of functional novelty than producer innovations. Building on their existing customer competence, users can come up with functional performance features that are valued by customers (Roy and Cohen, 2015). Innovations having a high degree of functional novelty offer new functionalities to address hitherto unmet user needs (Lettl et al., 2006b). Users tend to have superior knowledge about the shortcomings of existing market offerings as well as new needs, based on their own use competence (Lüthje et al., 2005; von Hippel, 1994b) or exchanges with other users (Franke and Shah, 2003; Hienerth et al., 2014; Lüthje et al., 2005) Even in the absence of first-hand experience of a use-related problem, their own user experience enhances their absorptive capacity (Cohen and Levinthal, 1990b) in relation to information shared by other users.

For producers, disruptive innovations of higher functional novelty are more difficult to develop. In contrast to users, producers often lack competences in identifying and selecting the most promising ideas with a high degree of functional novelty because they lack first-hand need knowledge (Chatterji and Fabrizio, 2013). Moreover, the specialized problem-solving and R&D capabilities which producers tend to possess are associated with the problem of “functional fixedness”, that is lower ability to think outside the box due to the barrier of familiar connotations of objects (Duncker and Lees, 1945). Radically new functionality is less likely to be the result of such specialized problem solving (Levitt and March, 1988; Nelson and Winter, 1973).

While paying little direct attention to disruptive innovation, the user innovation literature indicates that in many industries, functionally novel innovations are more likely to originate from users than from producers (Hienerth, 2006; Lettl et al., 2006a; von Hippel, 2005). For example, in their study of the furniture industry, Nishikawa, Schreier, and Ogawa (2013) find that users develop products characterized by higher levels of functional novelty. We hypothesize that:

*H4: Disruptive innovations involving a high degree of functional novelty are more likely to be developed by users than by producers.*

### *3.3.2 Degree of technological novelty*

Technological novelty captures the degree to which the product's components or architecture are substantially new (Afuah, 1998). Innovations with high technological novelty often render existing knowledge obsolete (Lettl et al., 2006b).

Disruptive innovations may but need not involve significant technological novelty. Some do, for example the video cassette recorder which was based on helical scan technology which at the time of its development was revolutionary. In contrast, other well-known disruptive innovations such as email, were based entirely on pre-existing technologies (or protocols). This variance, and even more its drivers, have received very little attention in the literature so far (Yu and Hang, 2010).

Mirroring our reasoning in the previous section, we expect the degree of technological novelty to be associated with the likely source of disruptive innovation, favoring producer innovators. Compared to users, producers are more likely to have strong technological competences. I.e., they have deep knowledge of technologies and are specialized in developing novel technological solutions to use-related problems in their market. Specialized expertise in a given field is associated with more efficient problem solving in this area due to the repeated execution of similar problem solving tasks which facilitates memory retrieval (e.g. Gobet and Simon, 1998). Producers can build on existing knowledge to come up with new technological solutions. Even if the new technology incorporated in a disruptive innovation is not based on the current technology base of the firm, producers are more likely than users to have experience in generic technology development processes and know-how. That is, they have higher-order technological competences in how to develop new technologies that lead to higher degrees of technological novelty in disruptive innovations.

In contrast, users typically lack technological competences and do not possess sophisticated technological know-how (Lüthje et al., 2005). Thus, user innovations often rely on bricolage, trial-and-error experimentation, and other quick-fix solutions which the user innovator deems “good enough” for his/her purpose (Lüthje et al., 2005; Raasch et al., 2008). Empirically, users have been found to be more easily over-strained by technologically advanced and radically new innovations (O’Connor and Veryzer, 2001; Veryzer, 1998). However, Lettl et al. (2006b) found that some innovative heavy users in the area of surgical equipment possess sophisticated technological knowledge and are able to spot and evaluate technological trends in advance. Nevertheless, in line with most of the literature, we argue that:

*H5: Disruptive innovations involving a high degree of technological novelty are more likely to be developed by producers than by users.*

### *3.4 Innovation characteristics: Type of innovation*

Finally, it is interesting to consider the differences in the likely sources of product and process innovations. Process innovations are new or significantly improved methods for production or delivery. They involve significant changes to techniques and procedures, equipment or software, employed to deliver a product or service (OECD/Eurostat, 2005). Processes are skillful and carried out to accomplish a non-trivial task (Hinsch et al., 2014). We argue that users and producers differ in their ability to generate process innovations due to their different knowledge sets and competences.

The development of process innovations is tied directly to the immediate usage of equipment. Equipment is not useful per se; it is useful only if and as it is incorporated into users' routines and systems of use. During use, users continuously build implicit knowledge about how to best employ the piece of equipment, how to adjust the usage process to different conditions, and how to combine it with other equipment (Hinsch et al., 2014). This knowledge derives from actual use experience and intimate engagement, and is typically tacit in nature, which makes it sticky and difficult to transfer (Faulkner and Runde, 2009; von Hippel, 1994b). Thus, in the development of process innovations, users have an epistemic advantage relative to producers, which is likely to affect their innovation activities (Lüthje et al., 2005). This advantage can be particularly strong in the case of disruptive process innovations. Their non-standard performance attributes make it much harder for producers to anticipate that users will want to employ their equipment in that particular way.

Although empirical research on user vs. producer innovations in processes and techniques is scarce, the few existing studies support this line of argumentation. Research shows that users are the primary source of techniques and procedures in the fields of medical and sporting equipment, for instance (Hienerth, 2016; Hienerth and Lettl, 2011; Hinsch et al., 2014). Users are also known to develop new techniques which trigger the development of new equipment (Faulkner and Runde, 2009; Hienerth et al., 2014; Lüthje et al., 2005; Raasch et al., 2008). Based on these considerations, we argue that:

*H6: Users are particularly likely to be the source of disruptive process innovations.*

#### 4. Methodology

To test these hypotheses, we used a historical content analysis approach based on extensive secondary data. Many areas and disciplines including marketing (Golder et al., 2009; Srinivasan et al., 2006), general management (Rhee and Fiss, 2014) and strategic management (Kotabe and Swan, 1995), and innovation research (Bianchi et al., 2011; Perks and Roberts, 2013) have fruitfully employed a similar approach. We use a longitudinal design in that we consider the market environment prior to the emergence of an innovation, as well as the history of the innovator.

We proceed in three steps which are described in detail below: sampling of disruptive innovations by means of a systematic literature review (section 4.1); extensive collection of secondary data on each innovation by two independent researchers which is summarized in 2-3-page case vignettes (section 4.2); and data coding by five independent raters (section 4.3). Our measures are described in section 4.4.

##### 4.1. Sampling

Our unit of analysis is the disruptive innovation. To identify such innovations, we conducted a systematic literature review (Tranfield et al., 2003) of the management research literature, searching for articles published between 1990 and 2013 in peer-reviewed management journals with a 5-year impact factor > 2.5 (Journal Citation Report, Social Science Edition 2012, journals related to the subject categories business and management). This included 40 journals<sup>1</sup>. For each, we used the same search string (“disruptive technology” OR

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<sup>1</sup> Academy of Management Annals, Academy of Management Journal, Academy of Management Perspectives, Academy of Management Review, Administrative Science Quarterly, California Management Review, Decision Sciences, Entrepreneurship Theory and Practice, International Journal of Management Reviews, Journal of the Academy of Marketing Science, Journal of Business Venturing, Journal of Consumer Research, Journal of International Business Studies, Journal of International Management, Journal of International Marketing, Journal of Interactive Marketing, Journal of Management, Journal of Management Studies, Journal of Marketing, Journal of Marketing Research, Journal of Organizational Behavior, Journal of Product Innovation Management, Journal of Retailing, Journal of Service Research, Journal of World Business, Leadership Quarterly, Long Range Planning, Management Science, Marketing Science, Omega-International Journal of Management Science, Organizational Behavior and Human Decision Processes, Organization Science, Organization Studies, Organization, Research Policy, Strategic Entrepreneurship Journal, Strategic Organization, Strategic Management Journal, Technological Forecasting and Social Change, Technovation.

“disruptive technologies” OR “disruptive innovation” OR “disruptive innovations”) to identify a match in the title, abstract, or keywords of their papers. This yielded 49 articles. After careful reading of these articles, we extracted a list of 62 case examples of disruptive innovation.

We also reviewed the seminal work of Christensen and his co-authors published in other outlets, particularly books (Christensen, 1993, 2011; Christensen et al., 2000; Christensen et al., 2009; Christensen and Raynor, 2010). This yielded a list of 74 cases.

Combining the two case sets and eliminating duplicates, resulted in a long-list of 131 cases. These cases were compiled in a database detailing the source, the disruptive innovation, the reference technology being disrupted, and the definition of “disruptive innovation” employed by the authors.

To obtain our final case set, we applied two simple selection criteria: First, we focused on cases according to the original definition of disruptive innovation which is confined to innovation in products and processes. This excluded 41 business model innovations, e.g. the cases of Amazon and Dell<sup>2</sup>. Second, we included only those cases identified precisely in the literature, which ensures that, for each instance, we are investigating a pre-identified case from the literature rather than related material in the same area. This criterion excluded 14 cases described in less specific terms, for example “modular construction” and “wafering”.

After applying these criteria, we obtained a short-list of n=62 cases (cf. Table 1) each of which we investigated in detail. The cases stem from several different industries, including consumer electronics, information and communication technology, healthcare, high tech, materials, and transport.

--- See Table 1: Description of case set in the Appendix ---

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<sup>2</sup> In his later work, Christensen extended the concept to include business model innovations (cf. Christensen & Raynor, 2003). To be conservative, we use his original definition since his broader definition has been criticized for subsuming rather different phenomena (e.g. Markides, 2006; Yu & Hang, 2010; Sood & Tellis, 2010).

Note that we could also have searched for case examples in the user innovation literature and investigated whether or not they were disruptive. We made a conscious choice not to follow this route to avoid sample bias in the direction of user innovations.

#### *4.2. Data sources and data collection*

For each case in our sample, two to three independent researchers collected extensive secondary data on the disruptive innovation, the innovator, and the innovation environment. Our more than 900 sources include scholarly writings, industry sources (associations, journals, databases), company sources (websites, annual reports), media coverage (press databases), and web-based sources (blogs, websites, forums). Based on the information gleaned from these sources, the authors produced case vignettes to a standard format covering the following aspects:

- (1) Innovation description:* Functionality, underlying technology, respective performance dimensions along which the innovation was perceived to be superior or inferior, compared to the disrupted technology;
- (2) Innovation history:* Description of the original innovator, first commercializer, IP protection, subsequent steps, and market success;
- (3) Environment prior to the innovation:* Appropriability regime, relevant customer groups, changes in demand, technological changes.

To enhance reliability, the data was collected by two independent researchers in areas (1) and (3), and by three independent researchers in area (2). Information regarding (2) innovation history was crucial, particularly as it related to identifying the original innovator and describing his/her motives to innovate. Across all cases and researchers, we applied a uniform definition to identify the original innovator: “the person, group, or organization that built the first functional prototype”. This definition excluded earlier actors who might have had an idea about what might be needed or what could be done but did not try to or manage to build a first prototype delivering the needed functionalities. In case of disagreement among the three researchers about the

identity of the original innovator, group discussions and additional data collection were undertaken until a consensus was achieved.

#### *4.3 Coding process*

Five independent raters, all with sufficient prior knowledge in the field of innovation management, coded the data summarized in our case vignettes. All raters received additional training with regard to the concept of disruptive innovation. To ensure reliability and unbiased assessment, the authors did not participate in the coding. All raters were provided with standardized coding materials and instructions (Krippendorff, 2004), specifically the case booklet containing all the case vignettes, a coding manual with explanations of the measures and the coding instructions, and a coding sheet to document the ratings. All were given personal face-to-face training related to the measures.

The coding was conducted in two steps. First, all the raters coded the focal variables with regard to (2) innovation history, which included our dependent variable, the innovator (user vs. producer). After three weeks, they rated the independent variables describing (1) the characteristics of the innovation, and at a later date, the variables describing (3) the innovation environment. This procedure was intended to minimize carryover effects from the coding of one variable to another, and thus to reduce common method bias.

#### *4.4 Measurement*

In this section, we describe our measures, starting with the dependent variable. Table 2 provides a complete overview. Unless stated otherwise, all the variables were rated by five coders.

Table 2: Overview of measures

Variable name	Function	Scale and Values	Cronbachs $\alpha$	Source
Functional inventor	DV: Innovator	<i>Nominal:</i> 1=User, 0=Producer, 99=Other	n.a.	Shah (2000)
Turbulence in preferences	IV: Environment	<i>Ordinal, 7-pt. Likert</i> 1="not discontinuous at all" to 7="very discontinuous"	.731	Tripsas (2008)
Technological turbulence	IV: Environment	<i>Ordinal, 7-pt. Likert</i> 1="technology is well established, not subject to change" to 7="technology changes often and in major ways"	.536	Calantone et al. (2003)
Strength of appropriability	IV: Environment	<i>Ordinal, 7-pt. Likert</i> 1="not effective at all" to 7="very effective"	.915	Derived from Teece (1986)
Functional novelty	IV: Innovation	<i>Ordinal, 7-pt. Likert</i> 1="not different at all" to 7="substantially different"	.641	Lettl et al. (2006)
Technological novelty	IV: Innovation	<i>Ordinal, 7-pt. Likert</i> 1="not different at all" to 7="substantially different"	.832	Chandy & Tellis (2000)
Type of innovation	IV: Innovation	<i>Nominal:</i> 0=Product, 1=Process	n.a.	OECD/Eurostat (2005)

#### 4.4.1 Dependent variable: Functional source of innovation

We coded the original source of a disruptive innovation as a producer innovator if the primary motive to innovate was economic profit, and as a user innovator if the motivation was own use. This is in line with the extensive user innovation literature (e.g. Shah, 2000). We applied this rule to collectives and individuals alike as innovators could be firms or individuals. While the motivation to innovate could be hybrid (Baldwin and von Hippel, 2011; Raasch and von Hippel, 2013; Stock et al., 2015), its exact composition is difficult to establish with any accuracy – particularly in retrospect, and based on secondary data.

In terms of inter-rater reliability, at least four of the five raters were in agreement about the type of innovator in the first round, for 74.2% of the cases, which is a high percentage. The remaining cases were discussed and additional information was sought where necessary, to achieve agreement in the second round.

#### *4.4.2 Independent variables: Characteristics of the innovation environment*

*Customer preference discontinuity:* This variable describes demand-side turbulence prior to the disruptive innovation, that is shifts in customer preference trajectories. Tripsas (2008) distinguishes four types of preference discontinuity: radical changes in the set of attributes considered by customers as they assess a product (through addition or elimination of attributes), radical changes in the relative importance attached to different product attributes, and radical changes in the minimum performance level, or maximum performance level required by customers. Our coders assessed all four types of preference discontinuity separately.

*Technological discontinuity:* This variable captures the technological turbulence present in the industry prior to the disruptive innovation (Calantone et al., 2003), that is, the frequency and degree of technological changes.

*Appropriability:* Based on the description provided in the case vignettes, three raters assessed the efficacy of formal IP protection in the industry in the time period analyzed.

#### *4.4.3 Independent variables: Innovation characteristics*

*Functional novelty:* Functional novelty refers to the degree of new/unmet user needs targeted by the innovation (Lettl et al., 2006b). The coders assessed to what extent the innovation "*incorporates a substantially different functionality for customers in comparison to previous products*", using a scale from 1='not at all different' to 7='substantially different.'"

*Technological novelty:* Technological novelty refers to the degree of new underlying technology incorporated in the innovation (Chandy and Tellis, 2000). Based on information about the principal technological

components of the innovation as well as those of established products, the coders assessed the magnitude of differences, using a scale from 1='not at all different' to 7='substantially different.'

*Type of innovation:* We distinguish product and process innovations according to the Oslo Manual (OECD/Eurostat, 2005) definition. Thus, products include goods and services as well as systems comprising both types of components. Processes include methods for production or delivery, and techniques and procedures involving the use of products.

## **5. Results**

### *5.1 Descriptive overview*

Of the 62 cases of disruptive innovation, 27 cases (44%) originated from user innovators and 27 from producer innovators. The innovators in the remaining 8 cases were what Raasch and von Hippel (2013) call participators, that is they were motivated chiefly by the benefits resulting from involvement in the innovation process such as fun, reputation, or learning.

With regard to their organizational affiliation, 14 innovators (23%) worked independently, 29 (47%) innovated in their workplace in a corporate setting, and 19 (31%) were employed by a research organization. Many user innovators were employed in research (52%), while the majority of producer innovators (85%) were from the corporate sector. Interestingly, 48% (13) of the producer innovators who created disruptive innovations were working at the time for an incumbent firm, and 74% of the user innovators were buyers of the incumbent product. These figures differ from the literature on the sources of disruptive innovation (e.g. Christensen and Bower, 1995, 1996) which stresses that disruptive innovations generally do not come from incumbents or their customers.

With regard to IP protection, the majority of producer innovators protect their innovations (54%), whereas users typically do not (73%). Producer innovators also tend to commercialize their innovations (69%), whereas only 17% of user innovators commercialize their innovation themselves.

Descriptive statistics and correlations for the focal independent variables are summarized in Table 3.

Table 3: Independent variables: Correlations and descriptive statistics

	n	min	max	mean	sd	1	2	3	4	5
1 Customer preference discontinuity	62	2.65	5.45	3.65	0.50	1				
2 Technological discontinuity	62	3.20	6.00	4.56	0.85	.232	1			
3 Strength of appropriability regime	62	1.00	6.00	3.41	1.71	-.06	.312*	1		
4 Functional novelty	62	2.00	7.00	4.11	1.04	.578**	.288*	.013	1	
5 Technological novelty	62	2.20	6.80	4.46	1.17	.236	.324*	.303*	.409**	1

\*\*\* significant at .001 level; \*\* significant at .01 level; \* significant at .05 level; t significant at .1 level

	Product	Process
6 Type of innovation	62	22

### 5.2 Findings

Initial analyses support five of our six hypotheses. Comparing user and producers innovators (ignoring the eight cases that could not be classified as either), the means differ significantly ( $p < 0.05$ ) in terms of the characteristics of the context in which they innovate, specifically its discontinuity with regard to customer preferences and technology and the strength of the appropriability regime, as well as the innovations they create, specifically the type of innovation they develop and its functional novelty. While producer innovators seem to create disruptive innovations involving greater technological novelty, the difference is not significant.

Table 4: Mean comparison

T-test

	Group	n	mean	sd	t	df	sig (2-tailed)	
H1_Customer preference discontinuity	User	27	3.863	0.470	4.2007	52	0.000	***
	Producer	27	3.364	0.399				
H2_Technological discontinuity	User	27	4.267	0.847	-2.0323	52	0.047	*
	Producer	27	4.724	0.808				
H3_Strength of appropriability regime	User	27	2.644	1.202	-3.7787	46.38	0.000	***
	Producer	27	4.175	1.728				
H4_Functional novelty	User	27	4.472	0.942	3.1224	52	0.003	**
	Producer	27	3.698	0.878				
H5_Technological novelty	User	27	4.039	1.101	-1.6691	52	0.101	
	Producer	27	4.550	1.147				

\*\*\* significant at .001 level; \*\* significant at .01 level; \* significant at .05 level; t significant at .1 level

Cross Tabs

	Group	n	Product	Process	Pearson Chi <sup>2</sup>	df	sig (2-tailed)	
H6_Type of innovation	User	27	11	16	11.435	1	0.001	***
	Producer	27	23	4				

\*\*\* significant at .001 level; \*\* significant at .01 level; \* significant at .05 level; t significant at .1 level

We further test our hypotheses by using multinomial probit and probit regression. For multinomial probit, our dependent variable takes three potential values (user vs. producer vs. other). The reference category is

producer innovator, and the results for “other” are not shown. For probit, we exclude the eight cases that could not be classified as either user or producer innovator, which resulted in a reduced sample of 54 cases.

We use a step-wise model to test our hypotheses (cf. Cameron and Trivedi; Horowitz and Savin, 2001). We calculate variance inflation factors (VIFs) by means of ordinary least square (OLS) regressions to check for multicollinearity among the independent variables in all the models. All VIFs are below 2.0, and thus below the critical threshold of 10, indicating no multicollinearity (Aiken et al., 1991).

The results of our six estimated models are displayed in table 5. Models 1 and 4 include only the independent variables relating to the innovation environment; models 2 and 5 incorporate only the product/process related variables; and models 3 and 6 integrate both types of variables in one model. All models show significant overall fit.

With respect to environmental variables, both the multinomial and the binomial probit model (models 1 and 4) provide full support for all three hypotheses ( $p < 0.05$ ) associating environmental factors and the source of innovation. In environments characterized by high turbulence in customer preferences, users are more likely to be the source of disruptive innovation, while technologically turbulent environments render it more likely that disruption will originate from a producer innovator. Also, a strong appropriability regime makes it more likely that disruptive innovation will come from producers; conversely, disruptive innovation in low-appropriability environments is more likely to come from users.

Our multinomial and the binomial probit models also support all three of our hypotheses associating the nature of the innovation with the type of innovator ( $p < 0.05$ ). Disruptive innovations characterized by high functional novelty are more likely to originate from user innovators. Conversely, disruptive innovations of high technological novelty tend to be developed by producers. Finally, users tend to be the source of disruptive process innovations, while disruptive product innovations are more likely to come from producers.

When we incorporate all the independent variables in one model, these results are mostly unchanged with the single exception that innovation type (product vs. process) is no longer significant. (For this model we take  $p < 0.1$  as a reasonable threshold of significance due to our small sample size and the large number of variables.) Also, strength of appropriability becomes insignificant for the binomial probit model (model 6), but remains significant in the multinomial probit model (model 3).

Table 5: Probit regression models 1-6: 1= User, 0=Producer

Variables	Multinomial probit <sup>1</sup>			Binomial probit		
	1	2	3	4	5	6
H1 Preference discontinuity	3.577*** (0.944)		4.818** (1.720)	3.007** (0.946)		2.963* (1.253)
H2 Technology discontinuity	-0.947* (0.381)		-1.179* (0.567)	-0.805* (0.324)		-0.698+ (0.408)
H3 Strength of appropriability	-0.573** (0.209)		-0.996* (0.440)	-0.519** (0.198)		-0.530 (0.332)
H4 Functional novelty		1.704** (0.528)	2.290* (1.043)		1.222** (0.405)	1.363+ (0.741)
H5 Technological novelty		-1.144** (0.404)	-1.900* (0.839)		-0.792** (0.291)	-1.159+ (0.598)
H6 Innovation type = Product		-1.688** (0.635)	-1.111 (0.931)		-1.157* (0.471)	-0.787 (0.665)
Intercept	-6.904* (3.041)	-1.059 (1.541)	-10.54* (4.958)	-5.675* (2.821)	-0.917 (1.222)	-6.547+ (3.855)
Observations	62	62	62	54	54	54
Log likelihood	-40.99	-38.11	-21.25	-19.06	-22.21	-13.06
$\chi^2$	22.160	20.280	17.820	36.750	30.430	48.750
p	0.001	0.003	0.121	0.000	0.000	0.000
McFadden R <sup>2</sup>				0.491	0.407	0.651

Standard errors in parentheses

\*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ , +  $p < 0.1$

<sup>1</sup> Reference category are "producers", results for "others (participators)" are not shown

To check the robustness of our results, we first check whether disruptions targeting B2B vs. B2C customers affect our results. To that end, we code all innovations accordingly and control for this type of innovation, clustering the standard errors in both groups. Our findings remain the same as in the main regressions; we find full support for our hypotheses in the multinomial regression ( $p < 0.05$ ) and in the binomial regression ( $p < 0.10$ ).

Second, we distinguished innovations originating from individuals vs. collectives (i.e. research institutes or firms). We recalculated our main analyses controlling for individuals and collectives as innovators, clustering the standard errors in both groups. Again, our findings remain robust to the inclusion of type of innovator (individual or collective); we find full support for our hypotheses in the multinomial regression ( $p < 0.01$ ) and in the binomial regression ( $p < 0.01$ ).

## **6. Discussion**

In this paper we investigated the sources of disruptive innovation. Thereby we sought to harness the complementarities but also reconcile the conflicting predictions in the literatures on disruptive innovation and user innovation, two influential research streams in innovation research. In line with the user innovation literature, we distinguished two sources of innovation – user and producer innovators. We derived and tested six hypotheses relating the characteristics of the innovation environment and the innovation to the likely source of disruptive innovation. Our empirical investigation relied on a sample of 62 historical disruptive innovations which we identified from a systematic literature review, secondary data from more than 900 sources summarized in 62 case vignettes, and content analysis and coding by multiple independent coders.

We found that 27 of the disruptive innovations in our sample originated from user innovators, and the same number from producer innovators. In the remaining 8 cases, the innovators had the characteristics of what Raasch and von Hippel (2013) call participators, that is innovators motivated by process-related benefits. As hypothesized, we found that users are more likely to be the source of disruptive innovations in environments characterized by high turbulence in customer preferences and weak appropriability regimes. In technologically turbulent environments disruptive innovations are more likely to originate from producer innovators. In terms

of innovation characteristics, disruptive innovations featuring high functional novelty are more likely to be developed by users, and innovations incorporating high technological novelty tend to come from producers. Finally, we found weaker evidence that users are more likely to be the source of disruptive process innovations, while producers are more likely to develop disruptive products and services.

### *6.1 Contribution to theory*

To our knowledge, this study is among the first to connect the literatures on disruptive innovation and user innovation. By advancing and testing hypotheses about the sources of disruptive innovation, we have tried to reconcile and extend these two influential research streams.

#### *6.1.1 Contribution to the disruptive innovation literature*

Unlike most of the disruptive innovation literature which is typically case-based and qualitative in nature (see Danneels, 2004, 2006; Sood and Tellis, 2010; Yu and Hang, 2010), the present paper employs a quantitative approach which aggregates and leverages extant case work. We sampled cases identified in the disruptive innovation literature to investigate quantitatively the emergence of disruptive innovation, as well as key explanatory factors. This methodological approach allows us to contribute to several aspects of the disruptive innovation literature:

First, to our knowledge, the present study is the first to investigate the origins of disruptive innovations, that is, their original source prior to commercialization. Thereby we add to the understanding of the early development phases of disruptive innovations, which to date is largely neglected in the literature. This seems an important gap given that current debate on the ex-ante identification of disruptive innovation and the disruptive susceptibility of value networks (Keller and Hüsig, 2009; Klenner et al., 2013) hinges critically on a thorough understanding of the origins of disruptive innovation. By linking contextual conditions such as environmental dynamism and appropriability, with the likely source of innovation, we indicate the most likely source of disruption.

The results of our quantitative examination of the original sources of disruptive innovation are partially in line with the literature but add some new perspectives. Specifically, we found that a significant proportion, 24.2%, of the disruptive innovations in our sample were *originally* developed by employees of incumbent firms, and 44% stemmed from users, 74% of whom were also buyers of the incumbent product. This is perhaps surprising since our sample contains innovations drawn exclusively from the disruptive innovation literature. These results complement findings that disruptive innovation tends to be come from outside the incumbents' core value network (Christensen, 2011; Christensen and Rosenbloom, 1995).

Second and relatedly, our findings of disruptive innovation coming from the customer domain inform the debate on the value of a customer or market orientation to identify disruptive innovations. They indicate that the perspective assumed in most of the disruptive innovation literature might be overly producer-centric. The literature suggests that depending on current customers for new ideas and product concepts is dangerous for incumbents since customers will only lead them to sustaining innovations (Christensen, 2011; Christensen and Bower, 1996). This notion is expressed in the quotes from Christensen (in sections 1 and 2.3) that his expectation would be for disruptive innovation to originate from sources other than customers and lead users of current products. Christensen's and his co-authors' works are cited frequently as grounds for not listening to (current) customers (Danneels, 2004; Yu and Hang, 2010) when seeking to identify disruptive threats. In the ensuing debate on the value of customer or market orientation for firm success (Hult et al., 2005; Slater and Narver, 1998, 1999; Slater and Olson, 2001), scholars emphasized the need to distinguish between customer orientation (focusing on expressed needs of mainstream customers) and market orientation (focusing on latent needs of emerging customers). Our findings inform this debate by addressing the underexplored question in which contextual conditions "listening to customers" for disruptive ideas is likely to be advantageous. We suggest that the value of customer or market orientation not only varies with organizational factors and competences (Hult and Ketchen, 2001; Hult et al., 2005), but is also contingent on the characteristics of the environment and of the disruptive innovation to be developed.

Finally, our research answers a call to link disruptiveness to other measures commonly used to capture innovativeness such as technological radicalness (Govindarajan and Kopalle, 2006a; Yu and Hang, 2010). E.g., using a new measure of disruptiveness, Govindarajan and Kopalle (2006c) uncover that disruptiveness and radicalness go hand in hand in some cases, but not in others. Our findings can explain some of this variance by connecting it to the source of the innovation, and also add granularity by distinguishing between functional and technological radicalness. Overall, we contribute to the body of work that seeks to show that “not all disruptive innovations are the same” (Markides, 2006, p. 24) and understand the drivers and consequences of these differences.

#### *6.1.2 Contribution to the user innovation literature*

From a user innovation perspective, our results may not seem surprising. Intuitively, we would expect users to be a frequent source of disruptive innovation due to their in-depth need information (Riggs and von Hippel, 1994; von Hippel, 1994b) and lack of concern over the cannibalizing effect of their innovation on incumbent product sales.

However, our study adds to the user innovation literature in several ways. First, we link the user innovation literature to discourse on industry evolution (Anderson and Tushman, 1990; Tripsas, 2008; Tushman and Anderson, 1986), a connection that has mostly been neglected in the literature to date (cf. Bogers et al., 2010). So far, there has been evidence from a small number of domains such as sports equipment (Baldwin et al., 2006) and juvenile products (Shah and Tripsas, 2007) that users played a major role in creating new market niches which subsequently grew in importance and thus attracted producer innovators (e.g. Faulkner and Runde, 2009; Shah and Tripsas, 2007). We found that, across a broad range of industries, users were behind many well-known disruptive innovations, which are known to have created entirely new markets and materially changed industry structure. Thus, we tighten the link between user innovation and thinking on product and industry life cycles, which (Bogers et al., 2010) identifies as “an important area for future research”.

Second, since our study is one of the very few (one of the few exceptions is Flowers et al., 2010) quantitative studies of user innovation spanning multiple industries, and uses rich information on the industry context, it can uncover contingency factors that favor either source of innovation, that is, users or producers. Thus, it contributes to theory building on the contextual conditions favoring user innovation – an issue that is under-explored in the literature (Bogers et al., 2010). Prior research shows that in some industries such as scientific instruments, user innovation dominates (von Hippel, 1976), while in other industries producer innovation prevails (von Hippel, 1988). The present paper offers new explanations for these inter-industry differences in the prevalence of user innovation, highlighting the influence of, for example, demand-side and supply-side turbulence.

Third, our study contributes to the emerging discourse linking user motivation to innovate and the development of new techniques. In the field of whitewater kayaking, Hienerth et al. (2014) find that new techniques are predominantly user-developed, while in the domain of surgical instruments, Hinsch et al. (2014) show how user-developed techniques prompt subsequent product innovation by producers. Our study contributes to this literature by providing quantitative evidence from a number of industries that new techniques (and processes more generally) tend to be developed by users.

While this was not the original goal of our study, it is one of the first pieces of research to provide empirical evidence of participators as a third type of innovator. Raasch and von Hippel (2013) propose that participators, that is, innovators motivated chiefly by the benefits associated with the innovation process, are a third pure type of innovator, alongside users and producers. Moving beyond case examples, the present study provides the first quantitative evidence that a substantial share of path-breaking innovations (13% of our sample), originate from participators – an important insight. One example from our sample is Philo Farnsworth, commonly acknowledged to have been the inventor of television. In 1920, Farnsworth, aged 14 had been tinkering with electric appliances such as telephones and generators and conceived the basic principles of television which he

pursued subsequently in his university studies. It was not until towards the end of his studies that his motivation shifted from the joy of exploration to commercialization and profit.

### *6.2 Limitations and future research*

There are some limitations to our study due mostly to our sampling strategy. We also suggest some directions for future research at the intersection of user innovation and disruptive innovation.

Our study relied on a sample of innovations pre-identified in the extant literature as disruptive. This allowed us to rely on accepted classifications of cases as disruptive innovation, and to study supposedly “typical” cases. In drawing on well-known cases from the literature with a focus on disruptive innovation by new market-entering producers, we would expect our sample to be biased against users as a source of disruptive innovations. This likely makes our findings on the proportion of disruptive innovations by users conservative estimates.

More generally, we cannot be sure that our case sample drawn from a systematic review of the management literature, is representative of disruptive innovations in general. For instance, we do not know the criteria on which the authors of previous disruptive innovation studies selected their cases. However, after a review of the selection criteria described in several of the papers, we see no reason why our sample should be biased with respect to the key variables investigated in this study (apart from the already mentioned potential bias against users).

We note also that our sample consists only of disruptive innovations. It would be valuable if future research could validate our results by including a control group of sustaining innovations, and comparing and contrasting the sources of innovation for these two types. While we believe that the inferences presented in this study are justified by our approach and results, future studies could shed light on additional questions relating to the sources of disruptive innovation.

Finally, our sample included eight disruptive innovations originating from participators, that is, innovators motivated by the benefits associated with the innovation process. This small number made it infeasible for us to investigate with sufficient precision, under what conditions participators would be the most likely source of disruptive innovation. Future research could explore this question and thus contribute to the emerging debate on participators as a third type of innovator not motivated by using or selling the innovation *output*, but by being involved in the innovation *process*. Future research could also investigate the extent to which participator innovations differ in character from user-developed and producer-developed innovations. Initial research on this provides some interesting insights (Stock et al., 2015) suggesting that this motivational distinction has broad implications for the nature of the innovations being created.

### 6.3 Managerial implications

Our findings inform managerial practice in incumbent firms concerned with the discovery of, and defense against disruptive threats. In practice, the principal challenge is timely identification of future disruptive innovations (Christensen, 2011). Disruptive changes have a positive net effect on industry growth but they change industry structure materially (Gilbert, 2003). Firms seeking to profit from disruptive innovations need to be able to identify potential ones at an early stage.

Firms' resources are scarce, and monitoring various potential sources of disruption under uncertainty to catch early signals is resource-intensive (West and Bogers, 2013). Our paper leverages the extensive literature on user innovation to support managers in the identification of disruptive threats. It provides guidance on “where to look” for disruptive innovations conditional on key contextual parameters. In other words, it supports the ex-ante identification of disruptive innovations and contributes to strengthening the predictive power of the disruptive innovation concept which according to a number of scholars, is not fully developed (Danneels, 2004, 2006; Govindarajan and Kopalle, 2006c; Klenner et al., 2013).

In addition, our findings highlight the conditions under which information exchange and collaboration with customers and users are particularly likely to yield disruptive ideas and innovations. In environments characterized by changing customer preferences and weak appropriability, producer firms are particularly likely to profit from integrating users' disruptive ideas in their innovation processes. E.g., they could integrate external lead users into the innovation process or draw on user units inside the boundaries of the firm (ROY). Our descriptive results reveal that users rarely commercialize their disruptive innovations themselves, and often do not even protect them by formal IP rights. This highlights potential complementarity with the producer domain in the exploitation of disruptive ideas generated in the user domain.

Finally, our quantitative results on the origins of disruptive innovation emphasize that managers of incumbent firms should not underestimate their employees' strengths in developing disruptive innovations: after all, 48% of producer-developed disruptive innovations in our sample originated in incumbent firms. A prominent example is the digital camera. Electrical engineer Steven Sasson invented the first digital camera in 1975 while working for the large incumbent, Kodak. Sasson tried to promote his prototype within Kodak but was given little support and was forced to drop the project. In 1991, 16 years later, Kodak commercialized its first digital camera, the DC-100 – years after the Sony Mavica (1981) and the MegaVision Tessera (1987). This example highlights that an outward focus can lead incumbents to discount potentially disruptive innovations developed in-house.

Table 1: Overview of case set (1/3)

#	Disruptive innovation	Description	Incumbent technology	Year of invention	Year of commercialization	Original inventor / Inventing organization
1	Bluetooth	Bluetooth is a wireless technology standard for exchanging data over short distances. It can connect several devices, overcoming problems of synchronization.	Short range data cables	1994	1999	Dr. Jaap Haartsen at Ericsson
2	Wireless LAN	A wireless local area network (WLAN) links two or more devices using some wireless distribution method (typically spread-spectrum or OFDM radio), and usually providing a connection through an access point to the wider Internet.	LAN	1970	1990	Norman Abramson
3	Wireless Mesh Networks	A wireless mesh network (WMN) is a wireless communication network made up of radio nodes organized in a mesh topology.	Centralized wireless communication methods	1973	1994	DARPA
4	VoIP	Voice-over-Internet Protocol (VoIP) is a methodology and group of technologies for the delivery of voice communications and multimedia sessions over Internet Protocol (IP) networks, such as the Internet. VoIP allows both data and voice to be transmitted via the same network.	Landline telephony	1974	1995	Danny Cohen
5	VCR	The videocassette recorder (VCR) is an electromechanical device that records analog audio and analog video from broadcast television or other source on a removable, magnetic tape videocassette, and can play back the recording.	Video tape recorders (VTR)	1969	1971	Sony
6	Flat Panel LCD Displays	Flat panel liquid-crystal displays are light and thin electronic visual displays. They are usually less than 10 centimetres (3.9 in) thick.	Cathode ray tube displays (CRTs)	1968	1969	George H. Heilmeier at RCA
7	Handheld Transistor Radios	A transistor radio is a small portable radio receiver that uses transistor-based circuitry.	Vacuum-tube radios	1947	1954	Herbert Mataré at Intermetall
8	Telephone	A telephone, or phone, is a telecommunications device that permits two or more users to conduct a direct conversation when they are not in the same physical space	Telegraph	1860	1877	Antonio Meucci
9	Television	Television, colloquially known as TV is a telecommunication medium that is used for transmitting and receiving moving images and sound.	Radio	1927	1934	Philo Farnsworth
10	Cell Phones	A mobile phone (also known as a cellular phone, cell phone, hand phone) is a phone that can make and receive telephone calls over a radio link while moving around a wide geographic area.	Fixed landline telephones	1973	1984	Martin Cooper at Motorola
11	Smart phones	A smartphone (or smart phone) is a mobile phone with more advanced computing capability and connectivity than basic feature phones.	Conventional mobile phones	1992	1994	IBM
12	Mobile internet	The mobile web refers to access to the world wide web, i.e. the use of browser-based Internet services, from a handheld mobile device, such as a smartphone or a feature phone, connected to a mobile network or other wireless network.	Fixed line internet services	1991	1996	Radiolinja
13	PC	A personal computer (PC) is a general-purpose computer, whose size, capabilities and original sale price make it useful for individuals, and is intended to be operated directly by an end-user with no intervening computer operator.	Mainframes and minicomputers	1950	1957	Edmund Berkeley at Columbia University
14	Ink jet printing	Inkjet printing is a type of computer printing that creates a digital image by propelling droplets of ink onto paper, plastic, or other substrates.	Laser printers	1948	1951	Rune Elmqvist at Elema-Schönander
15	Flash Memory	Flash memory is an electronic non-volatile computer storage medium that can be electrically erased and reprogrammed.	Volatile storage options	1980	1988	Fujio Masuoka
16	Microprocessor	A microprocessor incorporates the functions of a computer's central processing unit (CPU) on a single integrated circuit (IC), or at most a few ICs.	CPUs	1970	1971	Gary Boone at Texas Instruments
17	Photography	Photography is the art, science and practice of creating durable images by recording light or other electromagnetic radiation, either chemically by means of a light-sensitive material such as photographic film, or electronically by means of an image sensor.	Professional photography	1877	1888	George Eastman
18	Digital Camera	A digital camera (or digicam) is a camera that encodes digital images and videos digitally and stores them for later reproduction.	Analog camera	1975	1981	Steven Sasson
19	Household microwave	A microwave oven, often colloquially shortened to microwave, is a kitchen appliance that heats food by bombarding it with electromagnetic radiation in the microwave spectrum causing polarized molecules in the food to rotate and build up thermal energy in a process known as dielectric heating.	Conventional kitchen stoves	1945	1947	Percy Spencer at Raytheon
20	LED	An LED, or light emitting diode, is a semiconductor diode which, based on the effect of electroluminescence, glows when a voltage is applied.	Conventional lightbulbs	1927	1962	Oleg Losev
21	Pocket Calculator	An electronic (pocket) calculator is a small, portable electronic device used to perform both basic and complex operations of arithmetic. In 2014, basic calculators tended to be very inexpensive.	Slide ruler	1967	1970	Jack Kilby

Table 1: Overview of case set (2/3)

#	Disruptive innovation	Description	Incumbent technology	Year of invention	Year of commercialization	Original inventor / Inventing organization
22	Photocopying	Photocopying is the process of duplicating documents using xerography. A photocopier (also known as a copier or copy machine) is a machine that makes paper copies of documents and other visual images quickly and cheaply	Offset printing	1939	1959	Chester Carlson
23	3D printer	Three-dimensional (3D) printing, also known as additive manufacturing or stereolithography (SLA), is the process of using additives to form solid 3D objects of virtually any shape from a digital model.	Conventional manufacturing techniques	1980	1991	Hideo Kodama
24	Electric power tools	An electric power tool is a portable power tool that is driven by an electric motor and is used for the machining of materials.	Non-electric tools	1889	1895	Arthur J. Arnot
25	Operating system with GUI	An operating system (OS) is software that manages computer hardware and software resources and provides common services for computer programs. GUI (graphical user interface) OS include a graphical interface to control and use the OS.	Professional (non graphic) operating systems (UNIX or Apple based)	1973	1981	PARC (Xerox)
26	Free and open operating system	Free and Open OSs (e.g. Linux) are Unix or Windows-like operating systems that are free of charge and suitable for use on a wide range of computers and other products.	Conventional operating systems	1991	1991	Linus Torvald
27	Web-based office applications	An online office suite or online productivity suite is a type of office suite offered by websites in the form of software as a service. They can be accessed online from any Internet-enabled device running any OS.	Offline office applications			
28	Email	Electronic mail, most commonly referred to as email or e-mail is a method of exchanging digital messages from an author to one or more recipients.	Postal services	1971	1988	Raymond Samuel Tomlinson
29	SQL database	SQL (structured query language) is a special-purpose programming language designed to manage data held in a relational database management system (RDBMS), or for stream processing in a relational data stream management system (RDSMS).	Highly mathematical programming languages for relational databases	1974	1979	Donald D. Chamberlain, Raymond F. Boyce at IBM
30	Internet search engines	Search engines are programs that search documents for specified keywords and return a list of the documents where the keywords were found.	Offline directories	1990	1994	Alan Emtage, Peter J. Deutsch
31	Relational database	A relational database is a database that stores information about both the data and how they are related. Data and relationships are represented in a flat, two-dimensional table which preserves relational structuring.	Hierarchical databases	1970	1988	E.F. Codd at IBM
32	Grid computing	Grid computing is the collection of computer resources from multiple locations to reach a common goal. The grid can be thought of as a distributed system with non-interactive workloads which involve a large number of files.	Massive parallel processing (MPP)	1995	1999	Ian Foster, Carl Kesselman
33	DVDi	A DVD game (sometimes called a DVDi, "DVD interactive") is a standalone game that can be played on a set-top DVD player.	PC or console based games	1980	1983	David Lubar for David H. Ahl/ Creative Vomputing
34	mobile gaming	Mobile games are games designed for mobile devices, such as smartphones, feature phones, pocket PCs, personal digital assistants (PDA), tablet PCs, and portable media players.	PC or console based games	1990	1997	Texas Instruments
35	online gaming	Online gaming is a technology for connecting players of online games over some form of computer network, typically on the Internet.	PC or console based games	1973	1986	Steve Colley at NASA
36	Computer animation in films	Computer animation or digital animation is the process used to generate animated images using computer graphics.	Traditional comics and cartoons	1950	1958	John Whitney, Sr
37	CCGT	Combined cycle gas turbines (CCGT) combine the principles of both gas and steam turbines. In CCGT exhaust heat is used to power a peripheral steam turbine and generate more electricity.	Conventional gas turbines	1956	1970	Seippel, Bereuter at Brown Boveri
38	Hybrid Electric vehicle	A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs) which are powered by an electric as well as an internal combustion engine	Internal combustion engine car	1898	1902	Ferdinand Porsche at Lohner
39	Microturbine	Microturbines are miniature rotating machines that convert fluid energy into mechanical energy, implemented using microelectromechanical systems technologies or other small-scale manufacturing approaches.	Combined gas cycle turbines	1988	1998	Robin MacKay, Jom Noe at NoMac
40	Minimills	A steel minimill is a facility which produces steel products from recycled scrap metal. Unlike integrated steel mills which make new steel from iron ore in a blast furnace, mini mills melt and refine scrap steel using electric arc furnace (EAF) technology.	Integrated steel mills	1955	1989	Gerald Heffeman at Premier Steel Mills Ltd
41	Unmanned aircraft	The UAV or unmanned arial vehicle with no pilot, crew, or passengers on board. UAVs are defined as flying in the air with no person on board with capability controlling the aircraft.	Manned aircraft	1916	1918	Archibald Low at the British military
42	Plastics	Plastic is a polymeric material based on molecules of organic compounds and is one of the basic building blocks of our industry and everyday life	Other building materials (wood, metals)	1855	1866	Alexander Parkes

Table 1: Overview of case set (3/3)

#	Disruptive innovation	Description	Incumbent technology	Year of invention	Year of commercialization	Original inventor / Inventing organization
43	Electric vehicle	An electric vehicle (EV) or electric drive vehicle, uses one or more electric motors or traction motors for propulsion.	Internal combustion engine car	1828	1897	
44	Controllable optical films	Controllable Optical Films for Windows, colloquially in their context of application referred to as "Smart Glass", allow glass to change from transparent to translucent by blocking some or all wavelengths of light.	Conventional glass and shading technologies	1927	1937	Edwin H. Land
45	Internet	The Internet is a global system of interconnected computer networks that use the standard IP suite (TCP/IP) to link several billion devices worldwide.	Other means of communication and information aggregation	1969	1994	(D)ARPA
46	Phase change materials in construction	A phase-change material (PCM) is a substance with a high heat of fusion which by melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy.	Sensible heat storage	1948	2005	Dr. Maria Telkes at MIT
47	Packet switching	Packet switching is a digital networking communications method that groups all transmitted data – regardless of content, type, or structure – into suitably sized blocks called packets.	Circuit-switching technology	1961	1994	Leonard Kleinrock at (D)ARPA
48	DTCXO	Digital TCXOs (temperature compensated crystal oscillators) are digitally working crystal oscillators.	Analog TCXOs	1971	1984	Marvin E. Freking at Collins Radio Company
49	Sonography	Diagnostic sonography (ultrasonography) is an ultrasound-based diagnostic imaging technique used for visualizing internal body structures including tendons, muscles, joints, vessels, and internal organs for possible pathology or lesions.	X-Ray technology	1942	1950	Karl Dussik
50	Portable ultrasound	Portable / point-of-care ultrasound devices are ultrasound devices that are not fixed and stationary but instead are mobile and can be used directly at the point of care.	Stationary ultrasound devices	1972	1975	Marty Wilcox, Edward Dietrich at ADR
51	Drug-eluting stent	Drug-eluting stents are small scaffolds made of wire that are inserted into the narrowed coronary arteries of patients with atherosclerosis. The stent helps to hold the artery open and releases a drug that prevents any further blockage or obstruction occurring in the artery.	Bare metal stents (BMS)	1994	2003	Dr. Thomas Lambert
52	Portable X-Ray	Portable x-rays are small and lightweight radiography systems that can easily be moved from one place to another.	Conventional large-scale x-ray machines	1904	1919	Eugene W. Caldwell
53	Portable ECG	A portable ECG (electrocardiogram) is an ECG that can be used at the patient's bedside.	Conventional ECGs	1928	1928	The Sanborn Company
54	Portable Blood Glucose meter	A portable glucometer is a portable glucose monitor used to measure the amount of sugar in the blood, enabling patients to monitor their own blood glucose levels at home.	Stationary glucose meter	1967	1981	Stanley Clark
55	Micro Hydro	Micro hydro is a type of hydroelectric power that typically produce up to 500 kW of electricity using the natural flow of water.	Large-scale centralized hydropower generation	1903	1980	Hiram Chittenden at Yellowstone National Park
56	Nanofiltration Membranes for Watertech	Nanofiltration is a membrane filtration process used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter.	Conventional water purification methods	1954	1965	Samuel Yuster, Sidney Loeb, Srinivasa Sourirajan
57	Waste Water to Heat Technologies	Waste water energy recovery (WWER) systems can generate renewable energy from an already existing wastewater stream.	Conventional energy generation technologies	1938		
58	LASIK	Laser-assisted in-situ keratomileusis (LASIK) eye surgery is a procedure that corrects certain vision problems, reducing or eliminating the need for eyeglasses or corrective lenses.	Photorefractive keratectomy (PRK)	1983	1989	Stephen Torkel
59	Laparoscopic surgery	Laparoscopic surgery, also called minimally invasive surgery (MIS), bandid surgery, or keyhole surgery, is a modern surgical technique in which operations are performed far from their location through small incisions (usually 0.5–1.5 cm) elsewhere in the body.	Traditional / Invasive surgical techniques	1930		Dr. Fenvers
60	Angioplasty	Angioplasty is the technique of mechanically widening narrowed or obstructed arteries, typically to treat atherosclerosis. An empty and collapsed balloon on a guide wire, known as a balloon catheter, is passed into the narrowed locations and then inflated to a fixed size using water pressures some 75 to 500 times normal blood pressure	Bypass surgery	1964		Charles T. Dotter
61	Digital printing	Digital printing refers to methods of printing from a digital-based image directly to a variety of media.	Offset printing	1968	1968	Epson
62	MP3	MP3 (MPEG-1 or MPEG-2 Audio Layer III) is an audio coding format for digital audio which uses a form of irreversible data compression.	Compact discs (CDs)	1989	1994	Karlheinz Brandenburg

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