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TO OWN OR TO USE?

HOW PRODUCT SERVICE SYSTEMS FACILITATE
ECO-INNOVATION BEHAVIOR

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TO OWN OR TO USE?
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BEHAVIOR

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ABSTRACT

Increasingly firms develop technology-based sharing approaches where users rent, lease and share products, instead of purchasing them. Particularly, the product service system (PSS) concept has recently caught attention by scholars from different disciplines, although surprisingly little from the innovation research community. The writings from our colleagues however lead us to suspect that PSS developing firms might pursue an innovation behavior that is much more in line with recent societal demands for reducing environmental externalities. Recent examples show that adopting the PSS approach could be a way even for profit-driven firms towards a more sustainable economy, actually without too much governmental intervention.

However, to our knowledge this argument has yet been hardly discussed in detail. Drawing on concepts from the innovation management literature as well as from environmental management research, we contribute a model that explains why the PSS approach can shift firm innovation behavior towards generating fewer environmental externalities. This model links firm innovation behavior to three antecedents, including two product related characteristics (ownership, product purpose) and the specifics of the PSS related profit function. We argue that these antecedents differ whether firms develop products or PSSs. In the latter case the antecedent specifications impact firms' R&D objectives in a way that creates incentives to follow innovation trajectories that lead to a reduction of environmental externalities (i.e., eco-innovation behavior).

Keywords: Product Service System, servitization, innovation behavior, environmental externalities, ownership, corporate sustainability

INTRODUCTION

Capitalistic societies have been tremendously successful in increasing the material welfare of billions of customers through the provision of goods while at the same time negative externalities on the natural environment have become a serious issue. In these *consumption societies* more and more products are disposed at the end of their life cycles in ever increasing rates causing increased costs for society to protect the environment of hazardous effects (Krantz, 2010). Often particular firms' innovation behavior is accused of contributing to increased negative environmental externalities. While consumers demand the latest innovative products, firms are in an innovation race with its competitors developing innovative products in shorter times, wherefore product life cycles decrease again creating more waste due to their disposal, thus more externalities. Woeckener (1993) argued that almost every innovation is accompanied by a range of externalities that need to be counteracted by a stream of safety, health, and environmental regulations all aimed at protecting consumers and the environment in particular. While the extent of environmental externalities differs among innovations, certainly numerous innovations can be considered "improvements" in the sense that they cause fewer negative externalities than their predecessors (i.e. previous product generations).¹ For instance, today's flat panel displays consume less energy than formerly used cathode ray tube monitors. Although, on the contrary the replacement of cathode ray tube monitors and TV sets by flat panel displays has created a huge amount of WEEE (waste electrical and electronic equipment) (Huisman, Magalini, Kuehr, Maurer, Delgado, Artim & Stevels, 2008).

While there is hardly any product that does not create externalities in any stage of its life cycle (at least at its end), recent societal developments increasingly demand firms to adjust their innovation processes to develop products that reduce negative externalities (Hume, 2010; Seyfang, 2011; Sheth, Sethia & Srinivas, 2011). However, more efficient eco-products hardly seem to be sufficient, also entirely new approaches and business models are required. These include for instance the Cradle-to-Cradle (C2C) approach. C2C proposes that firms should design products already in a way that at the end of the life cycle their components become "nutrition" (i.e. positive externalities) to other products and processes (McDonough & Braungart, 2009). Alternative business models include the offering of solutions instead of selling products. In that context, particularly product service systems (PSS) have been advocated of creating potential beneficial effects for the environment (Mont, 2002; Tukker, 2004; Baines, Lightfoot, Evans, Neely, Greenough, Peppard, Roy, Shehab, Braganza & Tiwari, 2007).² In the innovation management literature, the PSS concept has been surprisingly hardly addressed so far, with some few exceptions (e.g., Hansen, Grosse-Dunker & Reichwald, 2009; Tietze, Schiederig & Herstatt, 2013). Applying concepts from innovation research, such as innovation trajectories and incentives-to-innovate, this paper should be understood as complementary to the existing literature.

In this paper we propose a more formal argument for why PSS innovations can contribute to diminishing environmental externalities. Essentially we argue that the PSS concept impacts firm innovation behavior towards more environmental friendly directions. We approach this theme by contrasting the specifications of three antecedents to the innovation behavior by product innovators with those of PSS innovators. The subsequent discussion leads us to propose a model that explains why the PSS approach leads to greater eco-innovation behavior.

¹ For an intense discussion see Fichter, Noack, Beucker, Bierter & Springer (2006) and Steger, Achterberg, Blok, Bode, Frenz, Hanekamp, Gather, Kurz, Imboden & Nutzinger (2002).

² Servitization approaches, such as the PSS concept, also can contribute to reduced threat of imitation, e.g., from far eastern firms.

The remainder of this paper is structured as follows. The next two sections define both essential concepts for this paper: PSS innovations and firm innovation behavior. The fourth and fifth sections present the three antecedents for firm innovation behavior that we include in our model. The sixth section discusses the impact of the antecedents on firm R&D objectives and consequently on their innovation behavior. The discussion section synthesizes the arguments into a model explaining how the PSS approach can lead to eco-innovation behavior. The final section concludes.

PRODUCT SERVICE SYSTEMS

Generally PSS relate to the combination of products with services (or services with products). This topic has been discussed in various disciplines and research communities often also under alternative terms: ‘functional innovation’ and ‘functional society’ in environmental and sustainability management (e.g., Tukker, 2004; Stahel, 2005; Aurich, Fuchs & Wagenknecht, 2006), ‘servitization’ in general management and service management (Vandermerwe & Rada, 1989), ‘product service systems’ in operations management (e.g., Isaksson, Larsson & Rönnbäck, 2009; Maussang, Zwolinski & Brissaud, 2009) as well as in the industrial design literature (e.g., Manzini, Vezzoli & Clark, 2001; Morelli, 2003). The subsequent discussion focuses on and applies the latter concept.

Baines et al. (2007) identified and reviewed existing and often cited PSS definitions. Accordingly, Goedkoop (1999: 18) was among the first to provide a formal definition for PSS as

“a marketable set of products and services capable of jointly fulfilling a user’s need... [The PSS] is provided by either a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. And product and service can be equally important for the function fulfillment.”

Following his definition others provided slightly adjusted and more precise definitions (e.g., Mont, 2001; Centre for Sustainable Design, 2002; Brandstotter, Haberl, Knoth, Kopacek & Kopacek, 2003; Manzini & Vezzoli, 2003; Wong, 2004; ELIMA Report, 2005). Recently, McDonough & Braungart (2009: 111) also provided a definition for PSS however labeling the concept as “product of service”. Accordingly, they describe PSS as

“instead of assuming that all products are to be bought, owned, and disposed of by ‘consumers’, products containing valuable technical nutrients – cars, televisions, carpeting, computers, and refrigerators, for example – would be reconceived as services people want to enjoy. In this scenario, customers (a more apt term for the users of these products) would effectively purchase the service of such a product for a defined user period..., rather than the ... [product] itself.”

In this paper we adopt a rather narrow understanding following the recent definition proposed by Tietze et al. (2013) that is somewhat similar to the functional PSS type described by Tukker (2004). According to their definition PSS incorporated five characteristic elements. While the first two of them are incorporated in most existing definitions, three elements narrow the scope of approaches included in the PSS notion. First, PSS are considered integrated offerings of tangible products, intangible services, and an enabling infrastructure. Second, PSS provide a product-unspecific functional use value (e.g., “flawless mobility” instead of purchasing a new

car and bike). Third, no ownership transfer takes place to the user of PSS solutions. Fourth, an enduring contractual relationship exists between users and an offering firm (i.e. instead of a single purchase contract as often characteristic for product sales). Fifth, the users become temporary proprietor enabling a high use-flexibility. Accordingly, Tietze et al. (2013) specified PSS as

“integrated offerings of tangible products, intangible services and the enabling infrastructure providing a product-unspecific functional value. Users and the offering firm engage in an enduring contractual relationship, but the ownership is not transferred to the users, who become temporary proprietors of the PSS product enabling a high use-flexibility”.

As noted above, some authors already mentioned that PSS can contribute to the reduction of environmental externalities caused by product manufacturing, utilization, and disposal (e.g., Baines et al., 2007; McDonough & Braungart, 2009). For instance, Mont (2002: 239) mentions four measures whereby PSS minimize the environmental impact of consumption:

“Closing material cycles and re-use of components in next generations; Reducing consumption through alternative scenarios of product use; Increasing overall resource productivity and dematerialisation of PSSs; Providing system solutions seeking the perfection in integrating system elements along with improving resource and functional efficiency of each element.”

McDonough & Braungart (2009) advocate that PSS have a potential to increase resource efficiency, but also enable the combination with other environmental concepts such as the Cradle-to-Cradle approach. While it seems unlikely that all PSS provide similar environmental gains, analyzing eight different types Tukker (2004: 259) studied PSS' environmental benefits in terms of factor-4 contribution potential (Weizsäcker, Lovins & Lovins, 1997) and found that primarily the “functional PSSs are probably the most promising types from a sustainability point of view.” On the contrary, the ecological downsides of PSS have been discussed to a limited extent only. Critics, such as Hertwich (2005) bring forward that eco-efficiency improvements can create rebound effects. For instance, highly efficient free-flowing car-sharing systems (e.g., car2go) can lead to over-utilization. While car sharing systems were generally found to be more environmental friendly than if every users purchasing own vehicles (Loose, 2008), the rebound effect could appear when they substitute the use of public transport with the use of vehicles provided through a highly efficient car sharing systems (A Greening, Greene & Difiglio, 2000; Berkhout, Muskens & W Velthuijsen, 2000). This discussion however largely focuses on the user perspective. In contrast to individual focused consumption pattern, the model proposed in this paper focuses on the firm level, particularly firms developing and offering PSS (i.e., PSS innovators), their innovation processes and the impact of PSS on firm innovation behavior. We ask particularly: how does developing PSS solutions - in contrast to selling products - impact firm innovation behavior, specifically with regard to environmental externalities?

FIRM INNOVATION BEHAVIOR

As the second central concept in our model we need to define firm innovation behavior. As we apply a dynamic perspective (i.e., how firms' adjust their innovation activities over time), we conceptualize innovation behavior as path or trajectory. The trajectory is determined by two dimensions. While firms innovate on the one hand to be economically successful, we are concerned with the impact of firms' innovation behavior on the natural environment.

Firms innovate primarily driven by economic incentives, for instance to increase profitability or maintain a competitive advantage. Pure profit maximization behavior (as advocated by classical orthodox economics and particularly the neoclassical theory) however gets increasingly criticized for not being aligned with today's society's expectations towards smart, sustainable, or inclusive growth (European Commission, 2010). Particularly with regard to ecological sustainability, society has widely realized the continuous overexploitation of resources, pollution of soil, water and the atmosphere (e.g., CO₂ emissions). After Brundtland (1987) coined the term "sustainability", nowadays a debate is ongoing that firms should aim to better align their economic objectives with the aim to manufacture and innovate "environmentally friendly". Hence, firms and the products they develop are expected to cause increasingly fewer negative environmental externalities.

To address society's demand a number of approaches and concepts (e.g., corporate sustainability, triple bottom line (TBL), corporate social responsibility (CSR), eco-efficiency, Cradle-to-Cradle) have been developed recently, primarily by environmental management scholars but with reception in the general management (e.g., Shrivastava, 1995; Bansal & Roth, 2000; McWilliams & Siegel, 2001). Most of these approaches however focus on firms' operational management and hardly on firm innovation behavior. Environmental policy supports these ambitions through numerous measures aimed toward industry (e.g., the European Union's Emission Trading Scheme - ETX (Ellerman & Buchner, 2007)) and subsidized R&D programs (e.g., the European Union's Green Cars Initiative). Although, yet to a limited extent, firms increasingly adjust to society's demand and adopt these innovative approaches. An increasing, although still little number of firms employs proactive environmental strategies which integrate the consideration of the natural environment into the concept of economic performance (Aragon-Correa & Sharma, 2003). While these measures aim to adjust firms' operational behavior, many firms still lack systematically accounting for environmental concerns within their innovation processes.

Although, undoubtedly numerous firms have made severe eco-efficiency improvements in recent years through the development of innovative technologies (e.g., Scania reduced the average 100km gasoline consumption of its trucks by almost 25% from 1990 to 2011), the success of their innovation behavior has remained to be primarily measured in economic terms. Despite firms' lack of implementing ecological objectives in their innovation processes also innovation management research has hardly addressed this issue. In a recent literature review Schiederig, Tietze & Herstatt (2012) identified just a mere of 136 papers published until 2010 that integrate innovation and environmental management research.

Within this paper we argue that similar to the extended understanding of firms' performance measurement the success of firm innovation behavior should not be solely assessed by an economic dimension, but be complemented with an environmental dimension. In economic terms, environmental impact is commonly expressed through the degree environmental externalities that firms or their products generate (e.g., through production waste, emissions or product disposal at the end of its lifetime). The United Nations (1997: 35) define externalities as "the economic concept of uncompensated environmental effects of production and

consumption that affect consumer utility and enterprise cost outside the market mechanism. As a consequence of negative externalities, private costs of production tend to be lower than its “social” cost. It is the aim of the “polluter/user-pays” principle to prompt households and enterprises to internalise externalities in their plans and budgets.”³ We propose that it is more than necessary to assess the results of firm innovation output not solely by economic measures (e.g., revenue contributions by innovative products), but also by ecological measures (e.g., degree of reduced environmental externalities as compared to existing alternatives⁴), if not additionally even by social concepts.⁵

Applying the trajectory concept, for this paper we thus propose to define firm eco-innovation behavior as a path (vector) within a bi-dimensional space opened up by firms’ economic and ecological objectives (Figure 1). Let us illustrate this conceptualization. A new innovation trajectory thus begins with the launch of a new product, that might also be categorized as a radical or breakthrough innovation (e.g., the launch of the iPhone as an entirely new product by Apple in 2007) (Sood & Tellis, 2005). However, firms hardly launch a sequence of entirely new product on the market. Instead, modern innovation conceptualizations acknowledge that innovation behavior can be interpreted as a cumulative process that builds upon previous discoveries generating a continuum of incremental improvements on some pioneer inventions (Scotchmer, 1991; Aghion, Harris, Howitt & Vickers, 2001; Murray & O’Mahony, 2007). Hence, we can argue that an entirely new product often determines a starting point for a new innovation trajectory from which firms’ innovation behavior follows evolutionary developing paths determined by the subsequent innovations through which the initial product is modified (e.g., over a number of future product generations). For instance, after its introduction of the iPhone in 2007, Apple followed an innovation trajectory along the launch of subsequent product generations, such as the iPhone 3G (launched in 2008), 3GS (in 2009), 4 (in 2010), 4S (in 2011) and 5 (in 2012). Despite that this example uses a product for illustrative purposes, the same argument applies for innovative services and combinations of product and services (e.g., PSS).

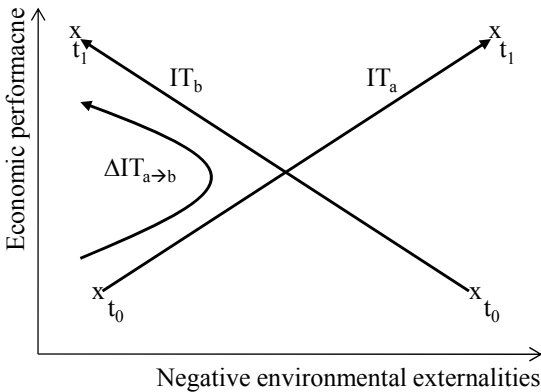


Figure 1: Firm innovation behavior as trajectory

Let us illustrate how our conceptualization can be interpreted with a small example. As depicted in Figure 1, in the bi-dimensional space opened up by the economic and ecologic dimensions,

³ See further, Henderson (1997), Koomey & Krause (1997), Elbasha & Roe (1996), Baumol (1972), Ayres & Kneese (1969), Buchanan (1962).

⁴ Similar to the definition of “green innovations”. See Schiederig et al. (2012) for a review of different definitions.

⁵ For the sake of our theoretical argumentation it is sufficient to assess the environmental success dimension on an abstract level (i.e. the reduction of negative environmental externalities). The operationalization of that concept is not relevant at this stage of our research and hence needs to be left for future research.

firms can pursue different innovation trajectories. Figure 1 depicts two particular innovation trajectories relevant for the arguments in this paper. Throughout the period t_0 to t_1 , the first innovation trajectory (IT_a) illustrates the innovation behavior of Firm_a that has become driven by increased economic objectives neglecting that thereby more negative environmental externalities are created. For instance, a publicly listed firm that has been pushed by increased shareholder pressure to increase its profitability through increased innovation speed (i.e. shortened market lead times), whereby more waste is created when consumers dispose precursor-generation products increasingly earlier. In contrast, IT_b illustrates the innovation behavior of Firm_b that has adjusted its innovation behavior within the period t_0 to t_1 towards reduced environmental externalities, while at the same time also increasing its economic performance. For instance, a firm has shifted its innovation behavior towards the development of processes to manufacture products cheaper while creating less waste per unit within the production process.

In the following we discuss how PSS innovations can contribute to trajectory shifts so that firms would adjust their innovation behavior to be aligned rather with IT_b than IT_a . We will argue that PSS has two distinctive impacts on the specifications for optimally designed products that firms would ultimately aim to use for offering PSS solutions (section 4). We will also argue that developing and offering PSS solutions leads firms to discover another profit function than selling products (section 5). The impact on product characteristics as well as the PSS profit function then has an impact on firms' R&D objectives (section 6) that cause them to ultimately adjust their innovation behavior.

PSS IMPACT ON PRODUCT CHARACTERISTICS

Having defined and discussed PSS innovations and firm innovation behavior we continue in this section to discuss two antecedents that we suggest to have an impact on firm innovation behavior. Therefore we contrast characteristics from the perspective of product innovators with the perspective of PSS innovators. We first compare distinctive differences with regard to the ownership situation along the product life cycle and then discuss differences with regard to the product purpose.

Ownership along the product life cycle

Product innovators commonly develop and manufacture products to generate value from product sales. During sales transactions, product ownership is commonly transferred to customers in exchange for a payment of an agreed sales price. As a consequence, product innovators have little economic incentive to care about *their* product after the ownership was transferred to a customer. Numerous daily examples exist that we are all familiar with.⁶

In such an ownership regime, product responsibilities are decoupled from the manufacturer through the sales transaction where the ownership is transferred to the customer. This transfer relieves manufacturers from their responsibilities to care for their products during later phases along the product life cycle, particularly the operating and disposal phases (Figure 2). While the ownership of the products remains with the innovating firm in the first phases (development and manufacturing), usually customers thereby acquire the responsibilities for operating and disposing the products through the ownership transfer. Hence, when product innovators

⁶ Exceptions to the rule course exist, for instance, if firms have possibilities to earn complementary revenues, e.g., through after sales services (such as maintenance) or the sale of complementary equipment.

determine product specifications within the innovation process they have hardly to account for the costs occurring during product use and disposal at the end of the life cycle. For instance, bicycle manufacturers have hardly any incentives to develop recycling schemes and leave the disposal of bicycles commonly to their customers. Only governments could cure this market failure, if they deploy policies forcing manufacturers through regulations.

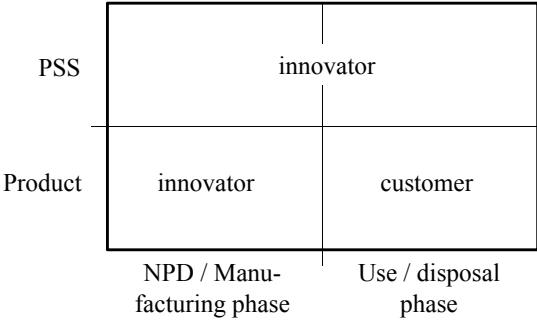


Figure 2: Ownership allocation for products along the life cycle of product and PSS innovators

Through the decoupling of ownership between the manufacturing and use as well as disposal phase another effect occurs. At the end of the product life cycle, customers who own a product often expect any further utility from disposing a product. Although some customers might disassemble their bicycles to keep a few spare parts, most have limited recycling competences and do not see how they can turn still functioning product components into (still) valuable goods, particularly if products are complex requiring specific equipment for disassembly. For instance, hardly any customer can recycle the components of used vehicles or electronic equipment. Consequently, customers are largely driven by one economic incentive, when facing the end of a product’s life cycle: to dispose the product for the lowest possible costs.

For PSS innovators the situation however is different. Following the PSS definition presented above, no ownership transfer takes place along a product’s life cycle that is used with a PSS offering (see also Manzini et al., 2001). While users become temporary proprietors of products, not at any time they gain ownership rights. Hence, users do not have to worry about product disposal as they simply return the product to the firm (of course, this is encouraged through financial deposits or contractual penalties).

This ownership constellation has another effect. Remaining product ownership with the manufacturer along the full life cycle enables PSS innovators full access to their products throughout the entire life cycle. Thus, manufacturers not only have an incentive, but also access to their products for continuously improving them throughout the life cycle towards minimum operating and disposal costs. Hence, they can implement innovative measures which they have developed at practically any time along the life cycle, without having to wait until they can launch a new product generation.

The product purpose

The PSS definition (see above) determines that products serve a different purpose in PSS offerings than for product innovators. As discussed above, product innovators sell their products to customers, while PSS innovators maintain product ownership and use their products as means for offering services to users.

In order to generate continuing revenue streams, it appears reasonable to assume that product and PSS innovators likewise aim to establish loyal relationships with their customers. However, here a distinctive difference can be observed: It is product innovators' objective to convince their customers to repurchase a new product once their currently owned product reaches end of life. In contrast, it is PSS innovators' objective to convince their customers to continuously reuse their products (Figure 3). The repurchase and reuse argument relates to the expectation-confirmation theory (ECT) (Bhattacharjee, 2001), which is widely applied in the consumer behavior literature.⁷

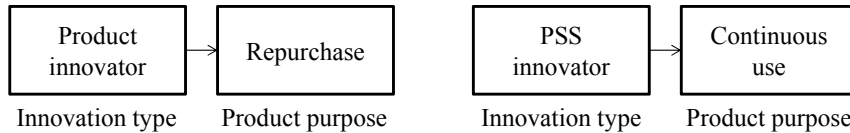


Figure 3: Innovation types and product purpose

Product and PSS innovators likewise will aim to contribute to product repurchase and reuse through optimizing their products. They commonly achieve this by adjusting the product design and manufacturing process through a stream of cumulative innovations so that the product develops towards optimally fulfilling customer expectations. Building upon the ECT theory, we argue that the different product purposes (repurchase vs. reuse) however translate into different performance requirements for the products that product and PSS innovators are likely to develop over time. These requirements translate into R&D objectives and heavily influence the firm's profit function. While the profit function is explained in the following chapter, in section 6 we explain in detail how different product purposes translate into different R&D objectives and thus lead to different firm innovation behavior.

A PROFIT FUNCTION WITH HIGHER POTENTIAL FOR INNOVATION

Due to the different ownership rights allocation along a product's life cycle and the different purposes that products serve (whether they are sold or used for PSS offerings) we argue in this section that the profit function of product innovators differs to the profit function of PSS innovators. Following common economic conceptualizations product innovators (PI) have the following profit function:

$$\prod_{PI} = q * p_u - c_{PI}(q)$$

$$c_{PI} = f(c_{NPD}; c_M; c_{SD}; c_{CI})$$

Equation 1 - Product innovator profit function

⁷ For instance, in order to study consumer satisfaction, post-purchase behavior (e.g., repurchase, complaining), and service marketing in general (Oliver, 1980; Tse & Wilton, 1988; Anderson & Sullivan, 1993; Patterson, Johnson & Spreng, 1997). The predictive ability of this theory has been demonstrated over a wide range of product repurchase and service continuance contexts, including automobile repurchase (Oliver, 1993), camcorder repurchase (Spreng, MacKenzie & Olshavsky, 1996), institutional repurchase of photographic products (Dabholkar, Shepherd & Thorpe, 2000), restaurant service (Swan & Trawick, 1981), and business professional services (Patterson et al., 1997).

Where revenues are the result of the quantity of sold products (q) multiplied with the per unit sales price (p_u). The product innovators total per unit costs (c_{PI}) can be split into four primary components. Product innovators face initial development costs for any new product (c_{NPD}), costs for manufacturing the products (c_M), costs for sales and distribution (c_{SD}) and costs for continuously innovating their products further (c_{CI}).

Hence, profit maximizing product innovators can optimize their profit function either by growing revenues (e.g., through entering new markets or pricing strategies) or through cost reducing innovations. Common measures to realize cost reductions are the development of process innovations in manufacturing processes (Abernathy & Utterback, 1978) or through optimized product design (Lai, Chang & Chang, 2005). For instance, following the development and launch of a new vehicle on the market as a product innovation, car manufacturer commonly start to reduce manufacturing costs for their vehicles though increased process automation. It is also common to continuously reduce per unit costs through incrementally adjusted vehicle design. For instance, expensive materials are sometimes replaced by cheaper ones with similar or just marginally lower performance properties that are still accepted by their customers (e.g., door handles made from aluminum are replaced by those made of plastic with a chrome coating).

In contrast, the profit function of PSS innovators (PSSI) differs substantially (Equation 2), not the least because PSS innovators retain ownership of the products they use in their PSS offerings throughout the full product life cycle. The revenues of PSS innovators are a function of the duration (d_t) for which one user utilizes one PSS unit, multiplied with the unit price per time unit (p_t) multiplied with the quantity of PSS units (q).

$$\prod_{PSSI} = d_t * p_t * q - c_{PSSI} * q$$

$$c_{PSSI} = f(c_{NPD}; c_M; c_{SD}; c_{CI}; c_{OP}; c_{MA}; c_D)$$

Equation 2 - PSS innovator profit function

Also the cost structure of PSS innovators is different. Instead of four, it rather includes seven primary cost components. PSS innovators total per unit costs (c_{PSSI}) include similar costs for new product development (c_{NPD}), manufacturing (c_M), sales and distribution (c_{SD}) as well as for continuous product improvements (c_{CI}). Additionally, they have to account for three components. As discussed above, PSS innovators remain the ownership of the products they use within their PSS solutions along the life cycle. Therefore, PSS innovators additionally have to account for the operating costs of the PSS units (c_{OP}), the costs for maintaining them (c_{MA}) and the costs for disposal or recycling of the products at the life cycle end (c_D). A closer look at the seven cost components actually leads to conclude that the PSS cost structure is similar to what is called the total cost of ownership (Ellram, 1993; 1995). In this particular case, total costs of ownership are even similar to product life cycle costs (Rebitzer & Seuring, 2003). Hence, by maximizing profits through cost minimization, PSS innovators can optimize product life cycle costs.

As the PSS profit function includes the cost components embedded in the profit function of product innovators, they have similar possibilities to minimize their costs. For instance, similar to product innovators, PSS innovators can lower product manufacturing costs through replacing expensive with cheaper product materials or through process innovations (e.g., automatized production facilities). Moreover, PSS innovators have an additional innovation potential. Due

to the additional cost components, which are not included in product innovators profit function, they have further possibilities to minimize their costs. They can also reduce their costs through innovations aimed at reductions of operation costs or costs arising from product disposal at the end of their life cycle. For instance, the car sharing operator car2go (a corporate spin-off from Daimler AG) developed the driver education program “EcoScore” and recently implemented it into its vehicles. During a ride EcoScore constantly visualizes the driver’s current fuel consumption in the vehicles’ dashboards through depicting trees that continuously growth or shrink, depending on the driver’s acceleration behavior. The software thus adapts a “gaming” approach generating an artificial competition, through which car2go attempts to incentivize the driver to reduce the vehicle’s emissions primarily for the benefits of the environment, despite of course that such measure contributes to the reduction of car2go’s own operating costs.⁸ Also, the vehicles used by car2go have been recently equipped with a start-stop-automatic that turns the engine off during driving brakes, e.g., at traffic lights or during traffic jams, thereby also reducing operating costs while also reducing environmental externalities.

Furthermore, PSS innovators can adjust the design of PSS products in order to reduce disposal costs at the end of the product life cycle. Possibilities include the development of innovative natural materials (e.g., such as Bamboo) and molding techniques to substitute toxic materials within product components allowing composting. Although economically motivated (i.e. by cost reduction incentives), a number of resulting incremental innovations can cumulatively reduce negative environmental externalities. Already at this point of our argumentation it becomes obvious that if PSS innovators develop innovations for reducing operating and disposal costs over time, one can actually expect to observe an evolution of specifically PSS optimized products that product innovators might not have developed.

PSS IMPACT ON PRODUCT RELATED R&D OBJECTIVE FUNCTIONS

In contrast to product innovators, the different product purpose, ownership structure, and profit function of PSS innovators have consequences for firms’ environmental R&D objectives. In the following we discuss the consequences for R&D objectives according to their position in the product life cycle. In the first two sub-sections *efficiency* and *consistency* are discussed which are important for products in the use phase. The subsequent two subsections *durability and reliability* as well as *maintenance and reparability* relate also partly to the use phase, but also to the end-of-life phase, because adjustments in these objectives can have an impact on the product’s lifespan. Ultimately, *disassembly and recyclability* relate to the end-of-life phase. It should be mentioned that the separation into R&D objectives is an analytical one, whereas in practice they overlap to varying degrees.

Product efficiency

While efficiency in the context of production is discussed widely, because it plays a major role for competitiveness, product efficiency has only recently become of interest. For instance, energy consuming long-life goods (e.g., cars, home appliances) have come to the attention recently, due to increased resource prices and stronger demands for environmental protection. Given the direct link between efficiency and the reduction of environmental impact, the term ‘eco-efficiency’ has been widely accepted (Schaltegger & Synnestvedt, 2002).

⁸ One should further mention that car2go operates only Smart vehicles that are already more fuel efficient than other vehicle types such as the A-class of Daimler.

Product innovators have however limited incentives to develop eco-efficient products. Since the sales contract makes them transfer the ownership of *their* product to their customers (see section 4), they have hardly any reason to develop more eco-efficient products. As long as product innovators ensure that their products perform efficient “enough” compared to competing products or marginally better, they can act risk averse and avoid investments in increased efficiency. Thereby they avoid uncertainty about whether customers would actually be willing to pay a price premium for the efficiency gains. Efficiency improvement is only pursued when this can be used as marketing argument (i.e., where they can use it as substantial sales argument with specific customer benefits). For instance, a car manufacturer might invest in more efficient engines, because this means lower fuel consumption and fewer stops at gas stations for their customers. Another driver for investment can also be other external focus (e.g., rising oil prices or governmental regulations). For instance, favorable conditions though fuel product efficiency in the white goods industry has dramatically increased through environmental regulation for new labeling schemes (e.g., the ‘EU Energy Label’ and the Japanese ‘Top runner’ program). Unfortunately, unfavorable regulatory frameworks can also cause negative effects, if they deemphasize the link between product efficiency and customer benefits. For example, cheap fuel prices allowed the US automotive industry to successfully sell vehicles with low fuel efficiency. These however, rather force product innovators to invest in eco-efficiency innovations, but hardly create internal incentives for them to pursue sustainable eco-efficient innovation behavior.

While the product innovator depends on customer consciousness and tougher regulation, product efficiency is in the self-interest of the PSS innovator. As PSS innovators remain owners of the product they use for offering their services, they can maximize profits, if they can minimize operating costs. Developing products with high eco-efficiency in the use phase minimizes operating costs and contributes to the PSS innovator’s profit function.

Product consistency

Next to efficiency, environmental management often emphasizes the importance of ‘consistency’ – a term generally describing resources and energy flows to be in harmony with the environment ((Huber, 2008); similar to the term ‘eco-effectiveness’ as used e.g., by Braungart, McDonough & Bollinger (2007)). Where efficiency is about quantity (i.e., externality reduction) consistency is about quality (i.e., use of harmless materials).

For both product and PSS innovators the substitution of environmentally damaging and toxic materials with more consistent alternatives can be an option in the manufacturing phase, in order to minimize costs arising from health risks of workers and other environmental risks in own production facilities and the entire supply chain. However, it remains unclear whether reduced risks compensate for the increased costs.

A comparable situation exists for the use phase of the product. In some cases, improvements in product consistency leads also to reduced risks for user, wherefore they are willing to pay a price premium (e.g., removal of harmful softening agents in plastics). However, in many cases the customer benefits is negligible and thus only interesting for niches with high ecological awareness, the complexities of materials and their chemical characteristics remains poorly understood by customers, or they remain entirely unknown (until campaigns by social movements increase public understanding).

Overall, it remains questionable if positive effects on the profit function can be achieved by the product innovator, because the main effects of product consistency are reaped in the product’s

end-of-life phase. This problem is particularly immanent, because product manufacturers do not own the products at the end of their life cycle. Thus, they hardly have incentives to avoid toxic materials which commonly create major costs, complexity and risks towards the end of the product's lifespan. Due to this reason, for instance, in Germany, several recycling facilities have been shut down by local authorities, due to unacceptable health risks, air and soil contamination with PCB and mercury from shredded products and materials.

Since PSS innovators remain the ownership of the products they use, they have to account for the disposing and recycling costs. They can reduce these costs, if they develop innovations to improve product consistency. Thus only the PSS innovator has substantial incentives to invest in consistency.

Reliability and durability

We have argued in section 4 (with reference to ECT theory) that product innovators strive for developing products in order to maximize their customers' propensity to repurchase them at the end of the life cycle. Thus, they need to develop products that meet the performance (or utility) expectations of their customers over a certain period (Figure 4).

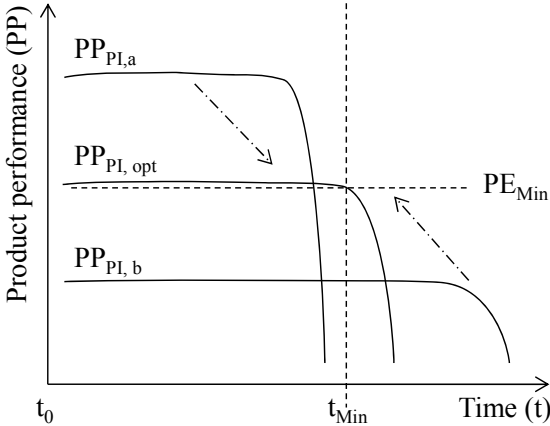


Figure 4: Product performance pattern development through innovation activities of product innovators

One can assume that a customer is likely to repurchase a product, if its performance remains above his minimum expected performance level (PE_{Min}) at least throughout his minimum expected lifespan (e.g., amortization period) ($t_{Min}-t_0$), where t_0 is the moment of product purchase. In other words, product innovators will set their R&D objectives to design their products in order to not disappoint customer's performance expectations until the customer has the perception that the product has paid off its price (amortization).

To illustrate how product innovators can optimize their products, let us briefly discuss two cases (Figure 4). First, Firm_a sells products with higher performance levels than expected from its customers, but the product performance decreases before the end of the customers' expected lifespan (see $PP_{PI,a}$). Firm_b sells products with lower performance levels than what customers expect, but the product's performance remains stable much longer than the customers expect it (see $PP_{PI,b}$). In both cases, the firms are likely to adjust their product design over time through a continuous stream of innovations (e.g., substituting materials) so that it sooner or later optimally complies with the customer's performance expectations (see $PP_{PI,opt}$), i.e. closely

above the expected performance minimum (PE_{Min}) for the expected lifespan (t_{Min-t_0}).⁹ For this purpose, product innovators conduct market analyses to understand their customers' expectations of the minimal product performance (PE_{Min}) and the expected lifespan (t_{Min-t_0}). Hence, while product innovators are likely to optimize their products not to undermine customers' expected performance minimum (i.e. avoid underperformance) before the end of the expected lifespan, they also have hardly any incentive to develop over-performing products (e.g., with higher performance or longer lifespans). On the contrary, they have actually incentives to design their products to break down after the "desired" time (i.e., planned obsolescence; (Guiltinan, 2009)). Because product innovators generate revenues through product sales, they rather avoid developing products that last substantially longer than their customers' expect. Additionally, longer living products are likely to be more expensive, for instance, because of higher prices for more durable materials.

In contrast, PSS innovators have to develop products so that their users continue to reuse their PSS idealistically over an infinite time. They have to ensure a steady performance level and can hardly allow any performance drop throughout the lifespan of the PSS offering. This is particularly important in settings of shared use (e.g., bike sharing systems), where even higher utilization rates of the individual product (by different users) commonly lead to higher stress on product properties, potentially causing product damages (Hardin, 1968; Feeny, Berkes, McCay & Acheson, 1990).¹⁰ Also, a product should not break down in use with one user that would then be not available for use of the subsequent user, who has maybe already made a reservation for that product. The systems of shared use, often with no or only limited fixed costs (e.g., monthly membership fee), allow users to switch immediately to an alternate PSS provider. Thus, in order to avoid disappointed customers, PSS innovators will design their products towards reliability, and specifically durability. For example, for many professional bike sharing systems in Germany it can be observed that providers have developed bicycles optimized for durability (e.g., strong frames, maintenance free gear pot) and are thus as reliable as possible.

Accordingly, the pattern of the performance expectation curve of PSS innovators is different to those depicted in Figure 4 for product innovators. A PSS innovator performance curve would be rather an infinite constant line, slightly above the minimum expected performance levels of different users. Since PSS innovators also cover the maintenance costs, they reduce their costs, if they can avoid maintenance operations, because their products are more reliable.¹¹

Furthermore, PSS innovators can maximize their profit function also through extending their *products' lifespans*. The fewer times they have to replace products, the higher are the product's revenue contributions. Thus, they have an economic incentive to develop their products towards longer lifespans. In line with other scholars (see above) we can thus argue that PSS innovators have incentives to innovate their products to life at least longer than those of product innovators.

Maintenance and reparability

We have already discussed the R&D objectives of reliability and durability aiming at the production of goods with superior quality and longevity. The R&D objectives of maintenance

⁹ Firm actually might even shape expectations. For instance, customers know when purchasing a light bulb that it should last 1000 operating hours. Thus, we do not expect them to last 2000 hours, even if this might be possible and desirable.

¹⁰ To design PSS products more durable is also necessary because overuse might occur due to the shared use by many users (i.e., tragedy of the commons).

¹¹ This conclusion is in line with what others have concluded for PSS solutions based on only partially similar arguments (e.g., Roy, 2000; Cooper, 2005; Kang & Wimmer, 2008).

and reparability are closely related as they ultimately also support reliability and durability. However, they do this less by improving the initial quality of the product (or product components), but more by incorporating the ability for maintenance and repair into the product design in order to reduce wearing down and fix failures respectively.

As product innovators gain large shares of their revenues from product sales, they are interested to maximize the amount of sold units. On the contrary, sometimes limited reparability may actually contribute to the profit expectation of product innovators. Thus, the business model of the product innovator focusing on sales of (new) products often makes maintenance and repair unattractive. Service fees for repair are sometimes deliberately set to a high level so that the customer perceives too view value in repair in comparison to purchasing a new product of the latest generation. An example is the iPhone, which requires the help of a service centre for the replacement of the battery. If the battery breaks down after a “sufficient” product use period, the customer might be willing to rather purchase a new iPhone instead of paying the repair fee.

The case is different for the PSS innovator. As they remain owners of the product in the use phase and have to cover the operating costs, they have an incentive to design their product so that maintenance and, in case product failure was unavoidable, repair occasions and thus costs are minimized. Here regular maintenance and repair often becomes cheaper than providing a new product. Wear parts/materials can be exploited alternatively and generate additional economic value as will also be explained next.

Disassembly and recyclability

One important issue at products’ end of life, is their subsequent treatment. While burning or landfill has dominated in the past, it becomes both economically and environmental more interesting to think of terminated products as resources or even nutrition (McDonough & Braungart, 2009).

Product innovators have limited incentives to care about recyclability and disassembly at the end of a product’s life cycle, because they do not have to account for the associated costs and can hardly maximize profits if they would invest in innovations to improve recyclability. The decoupling of ownership in the manufacturing phase and at the end of a product’s lifecycle can actually create counterintuitive effects. One of the most paradox examples is fluorescent lamp or “energy-saving lamps” – in the past often promoted as eco-innovation – which, however, creates serious problems in the end-of-life phase due to the heavy metal mercury. Refraining from toxic and otherwise harmful materials in the first place, makes recycling processes much more cost efficient and socially acceptable.¹²

As PSS innovators still own their products at the end of their life time, they can use “old” products as sources for inexpensive access to (particularly expensive) raw materials (e.g., rare-earths used in cell phones¹³) that can be reused for manufacturing new products. Moreover, they can directly reuse (particularly long life) components. Thereby, PSS innovators can reduce

¹² While we stressed the consistency of materials so far, consistency can also relate to a product’s resource and energy consumption in use as well as the underlying choice of technology. For example, in contrast to conventional cars, electric vehicles have the potential to use more consistent power sources (i.e., renewable energy). Still, as the user decides how and where to refuel the car, the firm usually cannot guarantee the consistent use of the car. The PSS innovator is however able bundle in their solution a green power contract to better control for the environmental impacts in the use phase.

¹³ The extent to what product and PSS innovators however realize this innovation potential depends on additional factors, such as raw material prices. With rising raw material prices recycling programs also become increasingly important for product innovators.

future manufacturing costs. Alternatively, components and raw materials could be sold to other firms generating additional revenues (e.g., primary plastic waste from hygiene products can be sold for reuse in frames of electronic equipment, such as TV or computer screens). In order to access raw materials and certain components for future product batches or generations, PSS innovators have thus an incentive to adjust the design of their products used within PSS solutions for quick and inexpensive disassembly already in the early innovation process stages.¹⁴

One might however argue that also product innovators have some limited incentives to design their products for recyclability. This is the case, if they can reuse certain components for manufacturing new products (thereby reducing their purchase costs) or at least access expensive materials cheaper than the market price.¹⁵ An example for industry responses is the “home appliance recycling program” of Panasonic. Together with Sharp and Toshiba, Panasonic set up the Electronic Manufacturers Recycling Management Company (MRM) in 2009. MRM recollects electronic equipment that product innovators sold to customers, e.g., for recycling of glass from old TV sets for new TVs and extraction of recyclable metals such as iron, copper and aluminum (Panasonic Group, 2010). However, while product innovators have to monitor the owners of the products they have manufactured and regain the ownership of these products, the recycling program costs can be expected to be much higher than for PSS innovators that retain the ownership of their products throughout the product life cycle anyhow. PSS innovators are likely to have much lower costs for harvesting raw materials and components from products which they still own and control at the end of their life cycle. Hence, the cost reduction potential serves as an economic incentive to pursue innovative activities to optimize products used within PSS offerings for easy disassembly for access to long-life components and expensive raw materials.

DISCUSSION

Classical business models in capitalistic societies, where firms develop and sale products should be questioned as a solution towards a sustainable society, because we observe that these cause severe environmental externalities. Hence, above we discuss an alternative approach where firms develop products to be used for offering services in so called “product service systems”. This final section synthesizes the above arguments integrating the perspectives from innovation and environmental management.

An integrated model

Table 1 summarizes the difference between product and PSS innovations elaborated above with regard to the three antecedents ownership, product purpose and profit function.

¹⁴ This argument also illustrates that the PSS approach is complementary with the cradle to cradle (C2C) approach (McDonough and Braungart, 2009). They claim that products should be designed for quick and easy disassembling so that the components and raw materials can serve as “nutrition” for other products.

¹⁵ In some markets firms are of course forced to develop recycling scheme through governmental regulations, such as ‘extended producer responsibility’ or the EU’s WEEE directive for electronic waste.

Innovation type	Product purpose	Product ownership	Profit function	R&D objectives
Product innovator	Repurchase	Decoupled: Transferred from manufacturer to customer	Split of lifecycle costs between manufacturer and customer	design to fail (planned obsolescences)
PSS innovator	Reuse	Remains always with PSS innovator	Total cost of ownership	Eco-efficiency, durability, recyclability, effectiveness

Table 1: Comparison of product and PSS innovator characteristics

From our arguments we can propose the following model that illustrates how PSS innovations can contribute to improved eco-innovation behavior. In other words, we provide an argument explaining how PSS innovations can shift firms' innovation trajectories towards directions that reduce environmental externalities. The model relates the three antecedents of firms' innovation behavior to firms' innovation success applying the bi-dimensional conceptualization of firms' innovation behavior presented above.

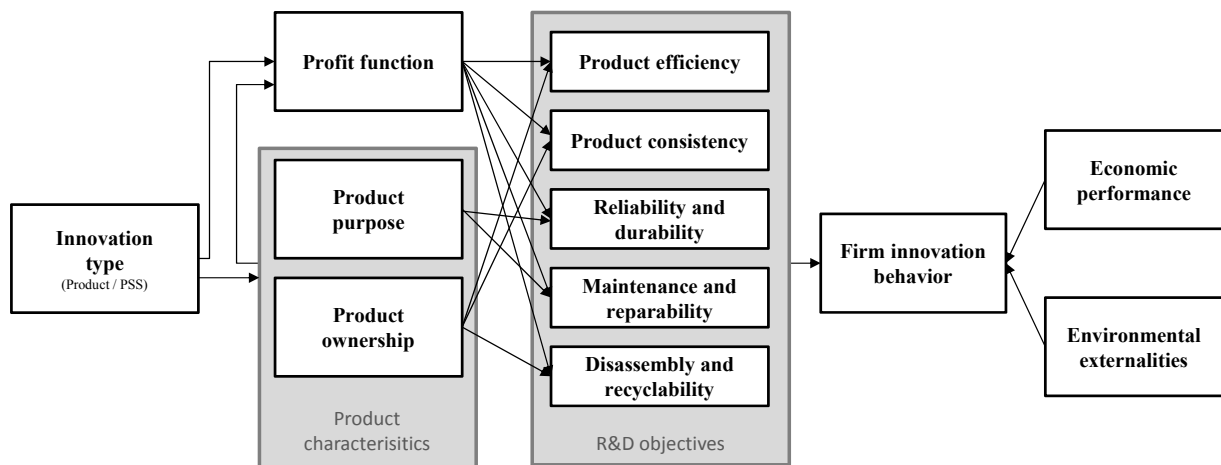


Figure 5: A model for the PSS impact on firms' innovation behavior

Products used in PSS solutions serve a different purpose than products that firms manufacture for sales transactions. While product innovators develop products for repurchase, PSS innovators develop products to be continuously reused. PSS innovators also remain the ownership of the products they use for offering PSS solutions along the lifecycle. Both substantial differences lead to a different profit function for PSS innovators in contrast to product innovating firms. Differences in these three antecedents then lead to R&D objectives that are well aligned with ecological requirements for eco-innovation behavior. Hence, the PSS concept creates economic incentives for firms to align economic and ecologic objectives and thereby contribute to fewer environmental externalities. The concept – and alternative sharing approaches - might thus be considered a promising concept for the future.

Evolutionary development from product to PSS innovator

With an increasing awareness that the classical sales based business model might not be the way forward towards a sustainable economy, one might question how product innovators can evolve to become PSS innovators. Product innovators are unlikely to become PSS innovators

ad hoc. This rather takes a stepwise transition process. We like to close this paper with a few thought on this process. At a certain point, an exogenous shock (e.g., strategic management decision) may trigger any firm’s evolution towards a PSS innovator (Figure 6).

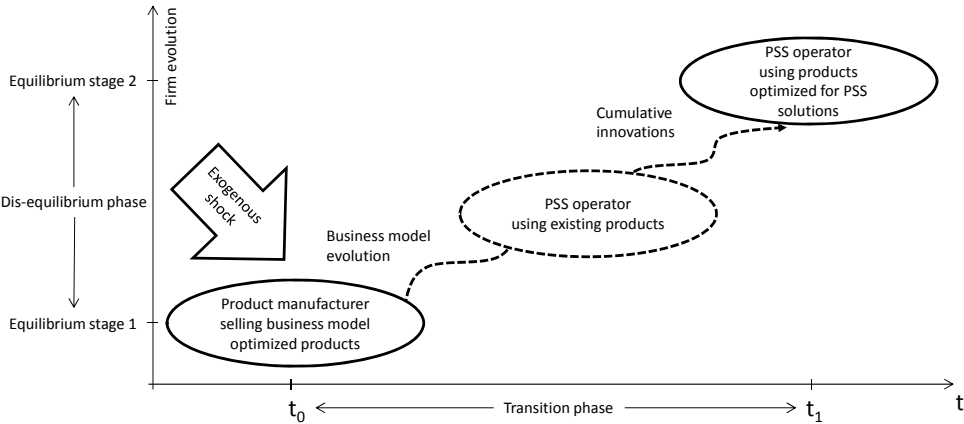


Figure 6: Firm transition from product innovator to PSS innovator

Following such decision, the business model of a firm (or division) and its accompanying processes are likely to change. While in this intermediate, dis-equilibrium phase the firm will adjust internal processes to offer a PSS solution as efficiently. It seems reasonable to assume that during this phase a firm tries first to utilize its existing products in the new setting of a PSS approach. However, those products might turn out not to be optimally designed to fit the new business model. An example from the mobility sector is again the car2go concept of Daimler. When initially the PSS offering was launched conventional Smart four two vehicles were used. After the PSS was running successfully for a certain period however, car2go started to modify the “standard” vehicles. For instance, solar panels were embedded into the roof of each vehicle in order to provide the necessary electricity to run the vehicle’s IT system (including GPS tracking), for the time when the car was parked and no running engine could provide the electricity. Hence, one can expect to observe that firms offering PSSs with product innovator roots will modify their products through a stream of cumulative innovations so that these optimally fit the new business model. Finally, the firm will arrive at a new equilibrium, where internal processes and its products are optimally suited for offering PSS innovations on the market.

Throughout the transition process PSS innovators are unlikely to directly address all R&D objectives discussed in section 6 ad hoc. Along the transition process firms will rather gradually address more and more of them. Due to the nature of the PSS profit function we expect that a PSS innovator will become more profitable (and thus stable) the more of the R&D objectives are addressed. We suggest that product innovators may evolve through four stages until they become fully optimized PSS innovators (Table 2).

Phase of PSS innovator	R&D Objectives addressed	Description
Experimenting	None (use of existing products)	When firms first experiment as PSS innovators, they will most likely use their existing products developed under paradigm of a product innovator. They will purposefully select the product to be transferred into a PSS solution. Most important, only more durable products are selected in order to guarantee high reliability and availability of the solution and therefore profitability in the new PSS business model.
Beginner	<ul style="list-style-type: none"> • Durability/ lifespan • Efficiency • Modularity/ reparability 	After initial experiences gained, the PSS innovator will start optimizing the product in order to boost the PSS profit function. Product quality is increased in order to secure a longer lifespan and less maintenance. Also, they are incentivized to reduced cost of product in use (e.g., electricity) through efficient products.
Established	<ul style="list-style-type: none"> • Design to disassembly • Consistency 	More established PSS innovators have gained considerable experience in the closed-loop production and consumption. They start thinking about how to increase benefits after product return. Therefore they invest in better design to disassembly so that they are able to more efficiently remanufacture or recycle the product after their return.
Advanced	<ul style="list-style-type: none"> • Radical technological innovation 	The most advanced PSS innovator will use the PSS business model to establish a technological first-mover strategy. They differentiate in the market through the introduction of radically new environmental technologies (e.g., electric vehicles) which they could not introduce as product innovator due to high price of product sales. In order to reap the first-mover advantage, this may even be done with premature technologies (e.g., batteries) - here trade-offs with efficiency, durability and other R&D objectives are accepted and controlled for through the service components of the PSS to prevent dissatisfaction of the user.

Table 2: Evolution towards optimized PSS innovators

CONCLUSIONS

Capitalist societies have become most successful in creating material wealth based on the concept of private property and the virtually unlimited provision of goods in modern production systems – at the same time environmental externalities have raised doubts in the status quo. The present paper is an endeavor to rethink the latter paradigm and to embark towards a capitalism in which the idol of private property and ownership of goods is partly replaced – where useful and practical – by systems of shared use and more specific, PSS innovations. The model proposed in the present paper explains how changes in R&D objectives make the development of PSS become better aligned with corporate self-interest and thus a more likely innovation path. We also discussed an evolutionary approach for turning from product to PSS innovator. Despite the need for future research and empirical testing of our arguments, innovation and environmental policy makers should consider developing favorable contextual factors that incentivize and support firms to make a smooth transition towards PSS innovators.

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